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JOURNAL OF THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

AND

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CONTENTS.

	PAGE
Council and Officers	i, ii
Committees	ii
General Notices:—	
Copyright	iv
Issue of Journal	iv
Changes of Address	iv
To Authors of Papers	iv
Communications	v
Appointments Register	v
Library	v
Review Section	v
Advertisements in the Journal	v
List of Advertisers	v
Personal Notes of Members and Special Notices	vi
Annual Report of Council for the year 1919...	vi
Second Annual Dinner...	109
Forty-second General Meeting, 16th December, 1919:—	
Paper: The Application of Liquid Fuel to Heavy-oil Engines, by A. J. Wilson, A.M.I.M.E., *Member* ...	141
Discussion: by the President, Mr. J. C. Templeton, Mr. N. A. Anfilogoff, Dr. W. R. Ormandy, Mr. J. L. Chaloner, and Mr. E. H. C. Craig	165
Subsequent communication by Mr. Percy Still	183
Forty-third General Meeting, 20th January, 1920:—	
Paper: Spontaneous Ignition-Temperatures of Liquid Fuels, by Harold Moore, M.Sc.Tech., A.I.C., F.C.S., *Associate Member*	186
Discussion: by the President, Mr. J. L. Chaloner, Dr. Ormandy, Mr. W. MacNab, Dr. F. B. Thole, Mr. E. A. Evans, Mr. N. A. Anfilogoff, and Dr. R. Lessing	211
The solubility relations of Castor Oil and Petrol from various sources, by William Ringrose Gelston Atkins	223

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

NOTICES.

The Institution as a body is not responsible for the statements or opinions expressed in any of its publications.

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Issue of Journal. The Journal appears in four parts per sessional volume, viz. in January, April, July and October. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed annually by revisions of the Library Catalogue and List of Members.

Members of all classes are entitled to receive these publications free: for additional copies of the Journal they will be charged at the price of five shillings per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel-Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel-post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible; and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of December, March, June or September as the case may be. Subsequent delivery may be too late for insertion.

Communications. The Council invite members to submit papers for the forthcoming session. Communications to the Institution will, subject to the approval of the Publication Committee, be published in the Journal.

Appointments Register. A Register will be kept at the Offices of the Institution for the convenience of firms requiring the services of members and for members requiring appointments, but on the distinct understanding that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library is in course of reorganisation in the new premises at No. 5, John Street, Adelphi, and may be consulted between 11 and 4 daily. Extensive additions are being made to the current and standard literature on Petroleum.

Review Section. It is intended to publish a quarterly review supplement containing brief accounts of current investigations in petroleum technology. Members are asked to communicate any such advances as are within their knowledge to the Editor.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry may be inserted in the Journal. Application for terms, etc., should be made to the Secretary.

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(Members are desired, when making enquiries or placing orders with advertisers, to mention that they have seen their announcement in the Journal.)

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

Sir THOMAS E. H. HOLLAND, K.C.S.I., K.C.I.E., F.R.S., is reported to have received the high honour of an appointment as Member of the Viceroy of India's Council. He is at present resident at Delhi.

Mrs. A. LLOYD EASTLAKE, so many years Secretary to the late Sir Boverton Redwood, Bart., has been appointed Librarian to the Institution.

Mr. WILLIAM SUTTON left for India in January.

Mr. E. LAWSON LOMAX sailed for India in January.

Mr. J. J. WHITEHEAD left for Lemberg on January 6th.

Dr. J. A. LEO HENDERSON has returned from a long visit to Canada, the West Indies (Trinidad), and the United States.

Mr. CHARLES DABELL has joined the staff of the Scottish-American Oil and Transport Co., Ltd.

Lieut. G. J. SAVAGE has been on active service on the East Persian Cordon, and is now on his way to the United Kingdom.

Mr. WILLIAM CALDER left for Persia on March 12th to take up the position of Assistant-General Field Manager for the Anglo-Persian Oil Co., Ltd.

Capt. T. E. G. BAILEY was killed on the Murman Coast during 1919.

ANNUAL REPORT, 1919.

The Institution on December 31st, 1919, had a Membership as follows :—

Honorary Members	7
Members	169
Associate Members	81
Students..... ..	19
Associates	11
Total	287

This gives an increase over 1918 of 33 Members, and a number of candidates were awaiting election.

The Statement of Accounts shows the financial position.

A most gratifying response has been made by several of the leading Oil Companies to the appeal by the Council for financial assistance for increasing the usefulness of the Institution.

The sales of the Journal for the year amounted to £146 4s. 6d., as against £113 15s. 0d. for the previous year, and the revenue derived from advertisements shows a moderate increase.

The large number of Journals sold is most satisfactory, as it shows the interest taken in the papers published.

Sir FREDERICK W. BLACK, K.C.B., has been re-elected President for the ensuing year.

The Rt. Hon. Viscount COWDRAY OF COWDRAY and Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S., Vice-Presidents, retire, and, being eligible, have been re-elected.

Mr. JAMES KEWLEY was elected a Member of Council on November 18th, 1919, and under the Bye-Laws he retires, and is nominated by the Council for re-election.

The Institution is represented on the :—

Conjoint Board of Scientific Societies.

Committee on the Extended Use of Oil Fuel in the Mercantile Marine, appointed by H.M. Petroleum Department.

Committees of the Imperial Mineral Resources Bureau on Abstracts, Publications and Libraries, and on Petroleum.

The Institution has acquired new offices at 5, John Street, Adelphi, London, W.C. 2, where members will be able to consult the books in the Library, together with the current scientific literature, between the hours of 11 a.m. and 4 p.m.

In view of the considerable additions to the Library and work in connection with the Journal, Dr. A. E. DUNSTAN has most kindly agreed to act as Honorary Assistant Librarian and Editor. Further exchanges with Scientific Journals have been arranged.

Since the last Annual Meeting the Honorary Editor reports that four numbers of the Journal, each containing two papers, have been published.

A new edition of the Library Catalogue, brought down to December 31st, 1918, with List of Members to June 30th, 1919, has also been issued.

The following list shows the wide range of the subjects treated in papers published in the Journal.

At the Thirty-fifth General Meeting :—" Paraffin Wax and its Manufacture," by A. CAMPBELL, F.I.C., and W. J. WILSON, A.I.C.

At the Thirty-sixth General Meeting :—" The Financing of Oilfields," by MONTAGU SUMMERS.

At the Thirty-seventh General Meeting :—"Plant Used in the Percussion Systems of Drilling Oil Wells," by MAURICE A. OCKENDEN, F.G.S., M.I.Mech.Eng., and ASHLEY CARTER, A.M.I.Mech.Eng.

At the Thirty-eighth General Meeting :—"Some War Problems of Petroleum Supply," by Sir FREDERICK W. BLACK, K.C.B., B.A. (Lond.).

At the Thirty-ninth General Meeting :—"The Chemist and Engineer in Relation to the Petroleum Industry," by Dr. F. MOLLWO PERKIN, F.I.C., F.C.S., and T. C. PALMER, Assoc.M.Inst.C.E.

At the Fortieth General Meeting :—"Some Laboratory Tests on Mineral Oils," by ARNOLD PHILIP, B.Sc., A.R.S.M., F.I.C., F.C.S.

At the Forty-first General Meeting :—"The Conservation of Oil," by Rear-Admiral (Retd.) PHILIP DUMAS, C.B.

At the Forty-second General Meeting :—"The Application of Liquid Fuel to Heavy-oil Engines," by A. J. WILSON, A.M.I.M.E.

The Library has received several donations, including a most handsome one from Lady REDWOOD, who has presented to the Institution the Technical Library of the late Sir BOVERTON REDWOOD, Bart., two microscopes, numerous slides and fittings appertaining thereto, models of an oil tanker and a Chinese Junk, several pictures, and a number of photographic slides.

The Institution has to deplore the death of three members, namely :—Mr. FREDERICK MILNE, Dr. A. U. M. SCHLAEPFER, and its first President, Sir BOVERTON REDWOOD, Bart., of whom a special memoir was printed in the June Journal, No. 20.

The first annual dinner, held on March 25th, 1919, was a great success.

The Council of the Royal Society of Arts have continued to afford the Institution the privilege of holding its meetings at their House.

The Council wish to express their appreciation of, and thanks for, valuable services rendered to the Institution by the Hon. Treasurer, Sir WILLIAM PLENDER, G.B.E., and the Hon. Auditors, Messrs. PRICE, WATERHOUSE & Co.

The Hon. Auditors, Messrs. PRICE, WATERHOUSE & Co., retire, and, being eligible, have kindly consented to agree to their re-election.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

Second Annual Dinner.

The second Annual Dinner of the Institution of Petroleum Technologists was held in the Connaught Rooms, Great Queen Street, W.C., on Tuesday evening, March 23rd, 1920, **Sir Frederick Black, K.C.B.** (President of the Institution), occupying the chair.

Among those present were :—The Rt. Hon. Walter H. Long, M.P., Sir Charles Greenway, Bart., Sir Hamar Greenwood, Bart., K.C., M.P., Sir J. D. Rees, Bart., K.C.I.E., C.V.O., M.P., Vice-Admiral Sir W. C. Pakenham, K.C.B., K.C.V.O., Rear-Admiral Philip Dumas, C.B., Capt. Sir A. E. M. Chatfield, K.C.M.G., C.B., C.V.O., A.D.C., R.N., Sir Marcus Samuel, Bart., Sir John Cadman, K.C.M.G., D.Sc., Admiral Sir Edmund J. W. Slade, K.C.I.E., K.C.V.O., General Sir John Cowans, G.C.B., G.C.M.G., M.V.O., Brigadier-General R. K. Bagnall-Wild, C.M.G., the Hon. Clive Pearson, Brigadier-General Sir H. C. L. Holden, K.C.B., F.R.S., Major A. Cooper-Key, C.B., Sir William Plender, G.B.E., Major R. W. Barnett, M.P., Sir Arthur Duckham, K.C.B., Dr. W. R. Ormandy, H. Barringer, Esq., Prof. J. S. S. Brame, T. G. Palmer, Esq., and A. W. Eastlake, Esq. (Hon. Secretary).

The usual loyal toast having been enthusiastically honoured,

Sir Charles Greenway, Bt., in proposing the toast of "His Majesty's Government," with which he coupled the names of the Rt. Hon. Walter Long, M.P., First Lord of the Admiralty, and Sir Hamar Greenwood, Minister in Charge of Petroleum Affairs, said it was a very great pleasure to him, as he was sure it would be also to the other members of the Institution, to welcome their guests there that night, as their presence—one of them being the founder and the other the present head of the new Government department known as the Petroleum Executive—might, he thought, be regarded as an official appreciation of the value of the work that was being done by the Institution of Petroleum Technologists in the direction of stimulating interest in this country in the study of the numerous scientific and technical problems connected with the geology, production, refining, transport and distribution of petroleum, and also in the training of experts in those various subjects. Much had been done already in this direction, but a good deal more had still to be done if this country was ever to secure the rank among the oil-producing countries of the world to which its naval and commercial position entitled it, and which he might even say was absolutely essential for its future existence.

It had been a matter of the very greatest gratification to all of those who were concerned in the development of the petroleum resources of the Empire to find that the Government had now recognised the great importance of the industry to the nation by considering it necessary to set up a special department of Petroleum Affairs. In the old days, when they had to seek the assistance or guidance of the Government in connection with their affairs—many of which were of an international character and of the highest Imperial importance—they were tossed and bandied about from one department to another, the Foreign Office, the Admiralty, the India Office, the Board of Trade, the Colonial Office, or the Treasury—and as often as not, when they thought they had succeeded in getting the support or views of the Government, they found that what had been said and done by one department was completely disavowed by another. The loss of time and of opportunities involved in that circumlocution were so enormous, and the advantages, not only to the industry but to the nation itself, to be derived from the centralisation of all petroleum matters in a department which could be relied upon, as he knew from experience, to give prompt attention to any question put to it, were so obvious that no word of his was required to point them out, and the only wonder was that the need for such a department was not recognised long ago.

Several of those present—amongst whom he would like specially to mention Sir Marcus Samuel, whom they had all great pleasure in welcoming there for the first time that night—had for many years past urged upon the Government the enormous importance of oil to the future of the Empire and the vital necessity which existed for ensuring ample British supplies of that precious commodity. When he had first raised his small voice in the wilderness of apathy which surrounded the subject, he despaired of ever seeing any interest awakened in the matter; but step by step since that time—largely due, he might mention, to the persistent and forcible representations of the founder of the Institution—he meant that great patriot and pioneer of the British oil industry, the late Sir Boverton Redwood—one member of Government or high official after another awoke to the dangers of the situation from a national point of view, until at last the stern lessons of the war had brought home incontestably to the Government the imperative necessity, for economic as well as defensive reasons, of developing to the utmost possible extent the petroleum resources of the Empire, and also of securing as far as possible control of supplies from other parts of the world.

Very few people had probably realised that throughout the war

this country was, in the matter of its oil supplies, on the brink of a most terrible danger—a danger which might at any time have forced it to seek an ignominious peace. As they all now knew, America and Holland might at any time have been forced by circumstances to come into the war against this country, or at least to have withheld from this country their supplies of petrol, aviation spirit, fuel oil, or spirit for the manufacture of toluol; in either of which events its position would, as all those present realised, have been absolutely hopeless. But, thanks to the wise counsels and skilful diplomacy of the leaders of those two nations, and of this country, and to the good offices of their friends concerned in the direction of the Standard and of the Royal Dutch and Shell Companies—notably in the last-named case, of Sir Marcus Samuel and Mr. Deterding—and also, if he might say so, partly to the good luck which always seemed to attend the British nation in its darkest hours—which good luck, by the way, they were sometimes smugly disposed to ascribe to the assistance that Providence always lent to a just cause—those dangers were averted. But he was sure his hearers would agree with him in thinking that those were dangers which they ought never to be called upon to face again, and that the British nation must henceforth do everything that was possible to protect itself in the matter of oil supplies; and that again in its turn necessitated the creation of a large number of British oil experts, which was what the Institution had set out to do. He had spoken of the members of Government and high officials who first became alive to the national importance of oil. Among those he should like to mention—more or less in the order of their entry into the arena of oil controversy—Lord Fisher, Lord Selbourne, Mr. Pretyman, Lord Curzon, the late Sir Gordon Miller, their chairman that evening, Lord Southborough, Mr. McKenna, Mr. Lloyd George, Mr. Churchill and Mr. Long. The eminent services rendered by Mr. Long during the war were well known to all of them. But it was not so generally known that at a time when, as Secretary of State for the Colonies, and later on when in his present position as First Lord of the Admiralty, his time and thoughts had been more than fully occupied with the great questions with which he had to deal as head of those Ministries, he undertook the arduous duty of forming a Ministry of Petroleum and acting as Minister thereof, and that he had also found time to organise, with the able assistance of Sir John Cadman and Mr. J. C. Clarke, the Petroleum Executive, which had had to deal—and had dealt most successfully—with many questions of the utmost complexity vital to the conduct of the war; and he thought he was expressing the feelings of all the

members of the Institution when he said that they viewed with the greatest possible admiration the success which had crowned his efforts and those of his able body of assistants. It was also a source of gratification to them that Mr. Long's mantle had descended upon so able and Imperialistically-minded a successor as Sir Hamar Greenwood, although he also would be, he was sorry to say, only what in business circles was called a "part time" man, inasmuch as with his duties as Minister of Petroleum Affairs he combined other important duties in the Foreign Office, and also in the Board of Trade; but he felt sure that he would, like Mr. Long, be fully equal to those manifold duties and be able to give due attention to the solution of the great problem which was now before the nation —that of securing ample supplies of British oil.

He did not want to occupy the time of the members for too long, as there were several other speakers to follow him; but with their permission he would like to recount a short personal reminiscence. He had spoken a little while ago of the representations which he had made from time to time on the subject of oil. One of the first of those was about 20 years ago on one of the banks of the Irawadi river, where Lord Curzon, then Viceroy of India, had given the late Mr. Kirkman Finlay (at that time Managing Director of the Burmah Oil Company) and himself an audience in very unusual but most picturesque surroundings. The *mise en scene* was the sandy bank of the river, a stranded log of teak on which Lord Curzon, Mr. Finlay and himself were seated, in the foreground the river and a number of launches and native boats in gala array, around them at a discreet distance the members of the viceregal party, behind them a great concourse of Shan chiefs and other gaudily-clad natives who had come down to pay homage to the great "Lat-Sahib," and behind them again the rugged bluffs of the Burmah oilfields. At that time a very strong movement was on foot which threatened the very existence of the Burmah Oil Company. They represented their case to Lord Curzon, who listened to what they had to say most sympathetically, with the result that the Burmah Oil Company had determined to fight for its independence. The outcome of that had been the great subsequent growth of that Company, and the foundation by it of the Company of which he had the honour to be chairman, and which would, he ventured to predict, one day be one of the most important oil organisations in the world. He thought he was correct in saying that the Burmah Oil Company had been at that date the only British Company (with the exception of the Scottish Shale Companies, which merely conducted a local business) which carried on the business of oil in

all its branches—producing, refining, exporting and distributing—without which ramifications independence in the oil trade was impossible; and therefore the place where the strange scene which he had just described occurred might, he thought, be quite justly regarded as the birthplace of British independence in the oil trade of the world, an independence which would, he hoped, in the course of time lead to this country securing the same position in oil that it now enjoyed in coal, and thereby maintaining the position it had always hitherto held—that of being the leading naval and marine Power and one of the leading industrial Powers of the world.

As a Past President he should have liked, before sitting down, to have said something about the objects and activities of the Institution of Petroleum Technologists, but as he had already occupied so much time he would leave that subject to subsequent speakers who would, no doubt, be able to deal more adequately with it.

He now asked those present to join him in the toast of "His Majesty's Government and the Government Services," and at the same time to drink to the healths of the Rt. Hon. Walter Long and of Sir Hamar Greenwood.

The Rt. Hon. Walter H. Long, M.P. (First Lord of the Admiralty), in responding, said he had very great pleasure in responding to the toast which had been proposed in such generous terms by Sir Charles Greenway, and if it at all interested those present, he desired to be permitted to state that the health of His Majesty's Government was much better than they would be inclined to believe if they placed reliance on the newspapers. (Laughter.) It was a common practice at the present day to circulate through the newspapers information as to the health of distinguished invalids, but as a rule the bulletins were signed by doctors who knew their patients and had confidential entry to the sick-room. Governments were treated in a different way. Their bulletins were issued by those who were very often not their confidential assistants and never had the entry of their sick-room. Therefore he ventured to suggest with great humility that bulletins as to the Government ought to be accepted with some reserve. They had recently heard that the Coalition Government was doomed, that it was not only in a moribund condition, but that in order to escape a death which it was not prepared, owing to its long record of black crime, to accept, it was endeavouring to make peace with its creator by reconstituting itself, so that by some form of rejuvenation it might escape an early dissolution. He thought he knew the inner secrets of the Government to which he had the honour to belong, and he could assure

those present that that was really the imagination of those who took a rather peculiar interest in the existence of the Government, and who were anxious to persuade people to believe a statement in regard to which those who made it must have a grievous doubt as to its truth. He was present at the dinner by virtue of the position he occupied as a member of the Ministry, as one who had been identified during the period of the war with the great industry which was represented at the gathering. He knew Sir Charles Greenway as one who occupied a high position in the commercial world and in the world of affairs, and who occupied it justly and by right of obvious ability. He knew that Sir Charles Greenway was a man to whom the Government owed a great debt for the services readily and splendidly rendered and for work well done: and when he addressed a gathering, those present naturally looked to him for words of wisdom. He confessed, however, that he had heard with some surprise one or two of the remarks Sir Charles had made, because it seemed to him Sir Charles could not have been as observant of our national character and traditions as he would have expected him to be, having regard to the undoubted abilities that he possessed. Sir Charles stated that he was surprised that we had not in this country paid attention before the war to the necessity for petroleum products, and he went on to say that he hoped the lesson that had been learned would be appreciated and taken home. That meant that Sir Charles Greenway, with all his great gifts and his wonderful opportunities, had failed to appreciate what the British people were. There were two things they never did. Firstly they never made preparation, and secondly they never took advantage of the lessons they had learned in time of adversity. There was one other thing, however, which they always did which was very different, namely, they always came out on top when they made up their minds to do so. (Cheers.) Sir Charles Greenway had stated that in 1917 the Prime Minister asked him (Mr. Long) if he would take charge of what he called Oil Affairs. He did not know what the Prime Minister meant. He did not know whether his duty in future was to find enough oil to light the lamp of the poor person in the East End, or whether it was to provide some oil with which to grease the wheels by which the Government machine was moving at the time, or whether it was his duty to provide oil to make glad the countenance of man at a time when everything tended rather to depress it. Those present would not blame him if he informed them that his reply was that he would like to consider the proposition before he gave a definite answer. Time did not permit him to tell what his experiences were; he would only state

what his first intuition was. He was then at the Colonial Office, and he thought the only reason why the Prime Minister asked him to undertake the duty was because at the time the Colonial Office was not concerned in the consumption of oil, and only remotely in its production. Sir Charles Greenway had stated that in the past all the departments took different views. That was because they were all consumers ; they were all interested in getting as much oil as they could for their own particular purposes. None of them thought of concentrating upon the utmost possible production ; none of them thought of economy of distribution or of simplifying the methods by which oil could be made available in due proportions for the various purposes for which it was required. Each one was paddling its own canoe, and therefore it was inevitable that when they had to come to decisions they arrived at results which conflicted one with the other. He had to look about him and make up his mind how he was to approach the task. He found confusion worse confounded. He would not reveal all that he learned, because he would be doing an unintentional injury to good men who gave their time and energy to the work, but who, he thought, failed to appreciate the real gravity of the situation with which they were confronted. One of the secrets of success in public life was to make up one's mind what one was going to do and how to do it, and he thought he might claim to have succeeded, because he had held high positions of State for a long period of time. Whether that should be regarded as the success of proved ability or the extraordinary powers of the limpet he would leave it to those present to decide. He made up his mind at once that the oil question must be solved, and he was not ashamed to admit that he took some assistance from the limpet, because he made up his mind at once that he must find the right man and give him his confidence and stick to him, and he found him in Sir John Cadman—(cheers)—who was the Petroleum Adviser of the Colonial Office. He called him to his counsels ; he told him what they had got to do, and from that day to the time the war ended he thought he could claim that what was now called the Petroleum Executive did really solve the very difficult problems with which it was confronted in its early days. What the country owed to Sir John Cadman for the work he did at that time and subsequently it was past his powers to describe. The Chairman, Mr. Ashdown, Mr. Clarke and many others worked with him on the Committee which was set up. He would not say more than that when they took over the very difficult task our tankers were being sunk ; oil was not reaching this country ; the Navy was in a parlous condition ; ships could not, very often,

leave their anchorages for want of oil, which might be required at any moment for naval operations; the Army was living on a ten days' or a fortnight's supply. That was simply due to the fact that there was nobody to co-ordinate the system by which supplies were brought together. That was the first task that had to be approached, and it was eventually accomplished. But other tasks also had to be accomplished. They had not only to secure for our own forces an adequate supply of oil, but they had to co-ordinate the supplies for the Allies. The result of that was a combination between this country and the United States of America, France and Italy—not at all an easy task. He remembered some of the interviews he had had with distinguished foreign representatives of those countries, and he remembered the very great difficulties that had to be overcome, which looked at the time to be insuperable. Nevertheless, they were overcome. Other difficulties at home also had to be faced, and the Committee called in to its aid from the very beginning the great supplying companies in this country. It was necessary to call upon them to make great sacrifices. Not only had they to pool all their resources, but they had to do something which went nearer home to them than that. In order to economise they had to agree to a method of distribution which meant a serious interference with their own trade in many parts of the country, which meant a very grievous sacrifice. But it was made. Those days were very black. They occurred at a time when our fortunes in the war were not in the ascendant, when day by day we were confronted with situations in France which made men ask what was going to be the end of the war. There were plenty of people in this country, although he was never one of them, who took a despondent view of the end of the war, who believed that the Allies could not accomplish the tremendous task which they had set themselves to do; and it was in those conditions that the difficult oil problem had to be faced. He was not, he believed, more ignorant than the great majority of his countrymen when he felt that he knew nothing on earth about the oil problem. It was a remarkable tribute to the inherent stupidity of our race, which was one of our greatest and most precious possessions, that we had gone on building oil ships for the Navy and for commerce, and laying down machinery which could not move a single wheel without oil to drive it, and yet we had not taken a single step to get the motive power without which all that had been provided would be futile. They had enlisted millions of men for the Army without a thought about the oil without which all would have been useless. He was glad that his honourable and gallant friend, a

most distinguished soldier, General Sir John Cowans, was present at the gathering. He hoped that some day the story would be told of the services that General Cowans rendered in winning the war. Sir John would remember, as he remembered, one or two interviews they had at the War Office when he talked to him in a friendly way about the steps that he was taking. He was not at all sure at the time that the public would support him or that the money would be forthcoming. He asked those present to remember what General Cowans did. Never in the whole history of the wars of the world had any army been fed and clothed as the British Army was in France and elsewhere. That not only occurred in France, because at a moment's notice General Cowans was told that he had to feed, clothe and equip armies in some other parts of the world, and he never failed. They were fed and clothed in a way in which soldiers had never been fed and clothed in the whole military history of the world. But all those stores of food and clothing could not have been moved if he had not had motor lorries to take the food to the places to which it had to be sent, and if there had been no oil the food would have rotted, the clothing would have lain on the quayside, and our soldiers would have gone hungry and naked—not because General Cowans had failed, but because the nation had forgotten that without oil in these days nothing could be done. Oil was a motive power. Ships moved by oil; the lorries that fed and clothed the troops in action moved by oil; machinery moved by oil; industry was dependent upon oil. He was a farmer and he was told that it was his duty to produce more food. He wanted to do so, and in order to do so he must have more machinery. Oil moved that machinery, and if more food was to be produced it was necessary to have more oil as motive power. A stage had now been reached when there were great factories filled with magnificent machinery; splendid ships of war and ships belonging to the mercantile marine had been built; every invention had been developed that science could think of in order to increase productive power; but if they had not oil all that was paralysed; no wheel could move; no lorries could travel; no soldier could get to the front to fight, and the men, women and children at home would starve. Why? Because it had been forgotten that in great progressive action without oil as the motive power they were reduced to absolute inaction. It had just been said by Sir Charles Greenway that oil was an essential aid to coal. It was more than that. A few years ago a committee made a report on the life of the coal supplies of this country. They knew the state of affairs that existed then, and they also knew that at the present time

there was a totally different difficulty to be met. Coal was essential to this country as a great productive power, and they knew that its supply might at any moment be cut down almost to zero by the action, whether right or wrong, of those who were concerned in its production. Was it not therefore up to those present to see that there was oil, not only because it was essential in itself, but also because it would greatly help to solve the problem of lessened coal production? He did not care from what point of view the question was approached—oil had become essential. He was not a lunatic on the subject. He had not attended the dinner to tell those present that oil was essential simply because those present were connected with the industry in various forms, but he had attended to say that it was wanted for the reasons he had mentioned. The late Sir William Harcourt, who was a great friend of his, once went on a political progress throughout the country and made five speeches, all the same. Sir William was a great orator, a man of great gifts, and he said to him afterwards: "In the name of heaven, explain to me why you, with all your gifts, made five speeches all the same." Sir William replied: "My dear fellow, for this reason: I had a particular thing I wanted to press home, and if you want to impress the British people you must say the same thing over and over again until you have convinced them. If you do not, you will never convince them." Many of those present had forgotten more about the subject of oil than he ever knew; they knew the essential necessity of oil to this country; and much would be done if they would go out as protagonists into the country and impress upon their fellow-countrymen what the command of oil meant. It was only necessary to think of the supplies that had recently been opened out in Mesopotamia, in Persia, and the undeveloped oilfields of the world. Great advantages had been obtained through the arrangements made by Sir Marcus Samuel and his colleagues. They were on the threshold of tremendous opportunities, and he asked those present to take care that they went on and occupied the house. The house was there, well built in all its proportions, splendid, glorious, ready to occupy. Would they occupy it or would they leave it to somebody else to do so? If they left it to somebody else they would hand over to that somebody else the key of all future success. Without motive power it was impossible to carry on either in peace or in war. He implored the members of the Institution not to be content with the splendid work which they were doing, not to think that because they knew all about it everybody else did so, but to try and realise that everybody else knew very little, that nobody in the country

realised the gravity of the crisis with which at any moment the country might be confronted. He hoped they would proselytise for all they were worth to make the country realise that one of the greatest needs of mankind was to secure in one form or another the command of those supplies which were waiting to be taken. If this country secured that command it could do what it liked, and if it could not get it it would fail, and those who came after would blame those present at the dinner for their inaction at a time of great national importance. He was very grateful to the members for drinking the health of His Majesty's Government, and he apologised for the length of his remarks, but unless they aroused the country to a sense of the real gravity of the situation in the future those who came after would rightly blame them for not acting as they ought to have done when the moment offered and the opportunity presented itself. (Loud cheers.)

Sir Hamar Greenwood, Bart., K.C., M.P., who also responded, said he had known Mr. Walter Long ever since he had the honour to sit in the House of Commons, now about 14 years, and he would never forget that Mr. Long paid to him the first and, he thought, the greatest compliment that had been paid to him during his Parliamentary career when he made his maiden speech. He remembered he was speaking on the vexed question as to whether or not Canadian bullocks should be admitted without undue inspection into the British markets. He held then, as he held now, that those splendid specimens of the bullock tribe were quite qualified, both on the bullock side and on the cow side, in view of their fine record, for admission to British markets. He made a tottering, stammering and rather incoherent speech, but Mr. Walter Long, who replied, encouraged him with a few complimentary remarks, and he had noticed ever since that Mr. Walter Long had maintained the great traditions of the House of Commons in showing courtesy and kindness to those who most needed it. Mr. Walter Long's record was better known to his countrymen than he thought; he stood for that class of straight, strong, courteous Englishmen who had elevated the public life of this country to a standard to which no other country could attain, although they all tried, and he had fixed the standard of patriotism so high that our public and Parliamentary life, in spite of transient criticism, was the envy of the world. (Cheers.) He agreed with the First Lord of the Admiralty that the health of the Ministry was good, from the Prime Minister right down to the junior member of the Ministry. They would go on; they would do their duty; they would leave their reward to the Almighty and their fate to

the electorate. (Laughter and cheers.) He was the successor of Mr. Walter Long as head of the Petroleum Department. That Department did good service during the war, and he intended as far as he could to make it justify its existence in the time of peace. It was the smallest Department of all the Government Departments, and the least expensive. There were only about 30 members of it and it might grow smaller. It was the ideal Department because every member was efficient and knew his job. The ideal of the Department was to be of national and, might he say, imperial service in developing the great petroleum interests of this country and of the Empire. The Department was particularly interested in the Institution; indeed, he looked to the scientific members of the petroleum world for developments in the production of oil that would make up at any rate for some of the shortage that was inevitable as the years rolled on, in endeavouring to make the supply meet the demand. Whatever his Department could do in helping towards the development of the production of oil from any source or in any way it would do it only too gladly. During the war period great quantities of oil were used; it was an indispensable article. In peace it was even more indispensable, and the quantities demanded were larger and would continue to grow larger. He looked forward to the future with great anxiety, because in many departments of human affairs throughout the world the demand was growing day by day and the supplies at the moment were not equal to the insistent and ever-growing demand. It emphasised the fact that they depended for supplies upon foreign sources. At least 70 per cent. of all the oil used in this country came from the United States, and only about 3 per cent. from our own Empire. He was not one of those who condemned the great companies whose sources of supply were outside this Empire, but whose markets to a certain extent were within it. He complimented them upon being pioneers in one of the great and indispensable industries of to-day and to-morrow. They ought not to be condemned but to be complimented. They showed that personal initiative, personal courage and personal risk of health and money had outstripped Government inaction, Government ignorance and in some cases Government sloth. He was one of those who believed that supplies were, if anything, more important than prices, but he wished to utter a word of warning, and he did so wishing well to all those engaged in the development of oil or any other industry that made for the well-being of mankind. It was true that great industries were being centralised and coming more and more under the control of individuals or of great corporations. But it must also be

remembered that masses and nations were becoming organised even more rapidly, and the time was coming when millions of men at the beckoning of an individual could act in the most violent—it might be the most foolish—way. It would be a bad thing for great corporations if they ever came into conflict with the masses of an indignant populace in this or in any other country, for it would result in a violence in which the masses were bound to win. He said, therefore, with great deliberation and with considerable anxiety as to the future, that it was in the interests of every great corporation, whether it be a Government corporation like that controlled by Sir Charles Greenway or any other, to keep in touch with the ever-enlightened and growing democracies throughout the world, who knew the origin and the cost of distribution of oil almost gallon by gallon, as well as those engaged in the industry. We were now dealing with a highly intelligent and a widely enlightened world, and he did not want to see conflicts in the economic sphere any more than he wanted to see them in the political sphere. He thought it right to say that, because he saw, not so much in this country as in others, a danger of great conflicts between the masses and the great interests which, properly conducted, were the servants of those same masses and democracies. Sir Charles Greenway had dealt with the celebrated palaver on the Irawadi. Sir Charles might wind up, for all he knew, as " My Lord Irawadi." (Laughter and cheers.) There had been wheat lords and beer lords and landlords, and there might be an oil lord before long, and if " Lord Irawadi " suited the first peer in the oil world it was not a bad title. (Laughter.) The word " Irawadi " reminded him of the far-flung frontiers of our Empire. It would not become him nor would it be fair for him to say anything that reflected upon companies whose supplies came from foreign countries, but he frankly admitted that he would like to see a large supply of oil coming from within the confines of the British Empire ; firstly in order to make the defence of the Empire, which primarily belonged to the Fleet, absolutely certain, and, secondly, because he believed the Empire, in the eloquent words of Lord Salisbury, was the greatest instrument for good the world had ever seen. He therefore desired to see it in its peaceful occupations have an increasing supply of an indispensable material without which mankind could not progress. Our many varied interests were not developed as they ought to be. He would like to see a larger supply within our own Empire, because he believed the more oil that could be produced the more rapidly would many conditions within the Empire that were not up to standards worthy of the tradition of the British race be ameliorated.

With that object in view, great efforts were being made to explore the Empire for oil, and many of those present were engaged in the quest. He wished them well, because he would like to see production so great within the Empire that, whether it be in war or whether it be in peace, this country would be in a position to defy the world. (Cheers.)

"THE NAVY, ARMY AND AIR FORCE."

Major R. W. Barnett, M.P., in proposing the toast of "The Navy, Army and Air Force," said there was a toast which, before the war, was always received with acclamation in any assembly of Englishmen, namely that of the Army and Navy. If that toast was drunk with acclamation before the war, with how much more fervour ought it to be drunk after the war, when both those forces had done such magnificent work. On the present occasion he asked those present to associate with the two senior Forces the Air Force, which had created a new chivalry of the air. This country started the war with a highly-trained professional Navy and Army. During the war the Navy had been splendid, as all Britishers knew it would be. If the German High Seas Fleet unfortunately mistook the Kiel Canal for the High Seas it was not the fault of the British Navy. (Cheers.) Probably for the rest of their days explanations would be heard from German admirals of how they won the Battle of Jutland. (Laughter.) He thought the best commentary on all the boasts of the German admirals was the excellent cartoon that appeared in Punch of a German dachshund which said to the British bull-dog: "You know I licked you. Why don't you go away?" (Laughter.) It was only right that with the toast of the Navy there should be associated the toast of the Royal Naval Reserve and the Royal Naval Volunteer Reserve, which did such splendid service in sweeping the sea clear of mines; and it was also only right that there should be associated with all those forces the men in plain clothes of the Mercantile Marine, who did such magnificent service for the country. In considering the toast he thought it was only natural to think mostly of the Army, because after all the miracle of the past five years was that England, the least military of all the Powers before the war, should have come forward and vied successfully with the greatest military Powers in the world. This country started with a great military tradition, a magnificent professional Army. He did not suppose that ever in the history of the world had there been a force superior to the seven Divisions that died for England in the mud of Flanders. In looking back upon the war one appreciated the splendid work those

men did. He sometimes thought that in years to come, when people looked back upon the war, that the things they would be most proud of were not the glorious victories which terminated the war, not the conquering of the Vimy Ridge nor the smashing of the Hindenburg line, but the holding out during the days of 1914 and 1915 in the retreat from Mons, the muddy trenches of Ypres, the fire of Hooge and the slag-heaps of Loos. It would be remembered in the future that a small force of men held out against enormous odds, and true to the national characteristic declined to admit that they were beaten. If men did not know that they were beaten, they were not beaten—that was a great psychological fact. The First Lord of the Admiralty had said that this country somehow or other possessed the trick of winning in the end, and it was the last battle that this country generally won. A Continental critic had said that the British always lost every battle except the last, but the last was the most important one of all.

He desired, in conclusion, to say a few words about the Air Force. If anyone had said at the beginning of the war that England was going to be predominant in the air, he ventured to think he would have been laughed at. Most of those who followed the experiences of the Air Force thought that people in this country were simply playing with it. We had inferior machines ; one or two men were killed every fortnight, and most people thought it was their fault for going up in such crazy craft. Within two months of the commencement of hostilities our Air Force had asserted itself ; within a year it was equal to any air force in the world ; within two years it was the best in the world. The Air Force was therefore worthy to take rank at the present time among the great historic forces that stood for the grandeur and dignity of this country. From among the distinguished officers which the Institution was proud to have as its guests, he had to couple with the toast a great sailor, Captain Chatfield, a great soldier, General Sir John Cowans, whose name was a household word in connection with the administration of the Army, and also Brigadier-General Bagnall-Wild, who, although his name occurred last, was by no means the least of the gallant officers present.

Captain Sir A. E. M. Chatfield, K.C.M.G., C.B., C.V.O., A.D.C., R.N., in responding on behalf of the Navy, said it was with great diffidence that a naval officer stood up in such an august assembly to reply to the toast on behalf of the naval services. It was a great honour for him to do so that evening, when he found seated on his right his chief, the First Lord of the Admiralty, and other distinguished officers such as Admiral Sir William Pakenham

and Admiral Sir Edmund Slade, officers at whose feet he had sat on various occasions in his efforts to acquire a knowledge of his profession. He was very glad to be able to reply to the toast of the Navy in view of the fact that he had recently occupied the post of Fourth Sea Lord, a post which he was deputed to fill in order to bring a little fresh sea air into the Admiralty. In the old days the sailor was very uneconomical in his use of oil. He used to pour it on salt water to keep it quiet; and that was all he knew about oil when he became Fourth Sea Lord. During the short time he occupied that post he acquired a good deal of knowledge on oil matters, and it became evident to him, as it must become evident to anyone in His Majesty's Navy who went to the Admiralty, that the interests of the Admiralty and the interests of the Institution were very much in common. If they were to solve the many great problems that lay before them in connection with oil, the consumers, amongst whom the Admiralty was one of the largest, must work in very close and kindly co-operation with the producers. He was also glad to be present that evening because the Board of Admiralty had recently been the subject of considerable criticism, and as threatened men lived long, it was satisfactory when a man had been threatened that he would be sacked, or meet some other fate, to find that he was still alive. Battleships and oil were very closely connected. Battleships depended upon oil, and he thought everyone would agree that oil depended upon battleships. A battleship was a very complicated mechanism—it was probably the most wonderful development of the human race. There was no trade or craft in any country, or hardly any craft, that did not find some expression in the construction of a man-of-war. If it was desired to trace the scientific development of maritime nations, it was only necessary to look at the men-of-war that had been produced in the past 50 years to obtain a very clear insight into the scientific progress, the richness and the power of the various nations. The development of the most important work of the country's defence could only be done by the most careful examination of many problems, and an investigation of all the lessons and scientific problems which had been learned during the long years the war lasted. The Admiralty took up its task at the present moment very much behindhand. The war did not give them time to study the problems of the day and to put into force the great lessons that had been learned. Many of the country's ships had been built in a hurry, without sufficient time to reflect on the lessons which had been learned; and it was the duty of the Board of Admiralty to see that the lessons which had been learned in the

war were applied to future construction. It was possible that the future might see the flying battleship or the submersible battleship, but personally he did not think it would, although he was not one of those who believed in what was called slow and steady progress. If a nation only progressed slowly and steadily it wasted a lot of time. It was necessary to look far ahead and be prepared to take a big step, but at the same time it was necessary to take care that the jump was made in the right direction. With regard to the question of oil and the Navy, the Admiralty made a great decision many years ago when, acting largely on the advice of Lord Fisher and Sir Marcus Samuel, it partially abandoned their good old friend King Coal, solid, steady, reliable and dirty, and followed that very attractive and captivating, but somewhat elusive lady called the Oil Queen. There was no doubt that the decision then arrived at was a wise one. Unfortunately, the Mercantile Marine, that steady and solid service, had also followed the Admiralty's lead, and some of them felt doubt as to whether their financial advisers would give them all the support that it was necessary to have in order to develop the oil resources of the country. They felt that they would lead them into the Bankruptcy Court or the Divorce Court. Although it would be a very good thing if oil could be found in the various portions of the Empire, that was not the same thing as having oil in our own country. If this country was to be able to rely with certainty on the mobility of its ships, independent of other nations, oil must be close at hand. Who could say to what extent it would be possible in ten years' time to bring oil from distant parts to this country in time of war? Warmly, therefore, as the Navy appreciated the toast which had just been drunk, he assured those present that the good wishes that had been extended to them were in no way comparable to the good wishes which the Royal Navy extended to the Institution in the great national work it was undertaking at the present moment. (Cheers.)

General Sir John Cowans, G.C.B., G.C.M.G., M.V.O., who responded on behalf of the Army, desired first of all to thank the First Lord of the Admiralty for his most generous and kind tribute to the work of the Quartermaster-General's department during the war. He could not take all the credit to himself, because the splendid work of the officers at the heads of the different departments under him contributed to the success of feeding, clothing and equipping the different armies in the various theatres of war. They all did their best, and very much appreciated the thanks that had been expressed to them. He felt it an honour to have been a member of the old little contemptible army,

after having served 40 years in the British Army. He could only pray that the new Army which was rising out of the ashes of the old one would be trained as well, mentally and physically, in order that it might uphold the glorious past of its predecessor. He felt sure he was not expected to say anything on the technological side of the petroleum question, but only to touch on it from the general point of view. All those present had been interested in their earliest youth up in different kinds of oil and its motive power, and had the greatest respect for it. (Laughter.) Generally, he thought, it might be said that oil was a very slippery substance. (Laughter.) It reminded him of a little verse that was hung up in his nursery :

> "If you your lips would keep from slips
> Five rules observe with care :
> Of whom you speak, to whom you speak
> And how and when and where."

He desired very much to endorse Captain Chatfield's remarks with regard to the absolute necessity of oil for the maintenance of the services of the Army. He could speak on that matter from experience. He well remembered the sleepless nights that he spent at the War Office in thinking over the oil question. At one period the amount of oil in hand represented less than a week's consumption, and it was a very serious question whether our men would be able to continue to hold the positions they held at the front. Certainly no advance could have been undertaken. That happened more than once during the war. He desired to thank all the Oil Companies for the great assistance they rendered to the Army during the war, particularly the Royal Dutch-Shell Group. He mentioned that because he was instructed by Lord Kitchener to go to them when the first difficulties arose, and they gave all their best brains to the solution of the problem. If the oil supply had failed it would almost certainly have meant the retirement of the whole line. The great Companies gave their help quietly and in an unostentatious manner, and he did not think they had been thanked half enough for what they did during that critical period. In the past the nation had been frightfully slow in recognising the necessity of the use of oil in all its operations. The country was, when war broke out, between 20 and 30 years behind the American and Dutch nations in its knowledge of oil. It was very difficult to make up that leeway, because it was impossible to train an expert geologist under 8 or 10 years' experience in a field, or at home in the technical part of the business. Putting aside the question of trained personnel, there were not at present within the Empire

territories upon which they could work. It might be said that practically half the oil territories were owned by the Dutch and half by the Americans; and until they had found their feet it was necessary to rely on one or other of those two nations. If this country did not play its cards well, people were likely to suffer far greater hardships during peace than they had in war, and at a far greater cost; and it might end in our mechanical transport and our ships being to a certain extent immobilised if war came upon the country suddenly. He had heard very optimistic opinions expressed with regard to the production of oil in Great Britain and its Colonies, but, personally, he thought it would be necessary to depend upon our friendship with the possessors of the other supplies in the world, from whom we obtained the larger percentage of our supplies. There were those 20 years ago who warned the British Government of what was going to happen, but he was afraid they only got the usual official *non possumus* stereotyped reply; at any rate they were not encouraged. If the oil, or any other, industry was to be fully, satisfactorily and rapidly developed, it ought to be done by private enterprise, encouraged by the Government. The Government had already embarked on one oil enterprise which had turned out to its very great advantage, and he desired to ask whether it would not be sound for the Government to use that fact to secure that friendship with others that was so vital, rather than to create any animosities which must necessarily arise from competitors who were carrying on enterprises of a similar nature. It reminded him of the Biblical character, Elijah, and the widow's cruse. For the moment he desired to regard the Government as the widow, whose cruse up to the present time had been kept full of oil. The widow had adopted a very sturdy little boy of Hindu-Burmese-Persian extraction, known as Apoc—the Anglo-Persian Oil Company, who was almost ready to start his future career in this wicked world. It was necessary for the widow to realise that as years went on she did not get more attractive; and should an opportunity arise for making a suitable match with a supposed wealthy family, he ventured to think she would do wisely to accept the offer, in case that family looked elsewhere for another alliance. (Laughter.) He only threw that out as a suggestion to the widow. He desired also to recall the words from a paragraph of the Report of the Sub-Committee on Petrol, namely: "In our opinion it is far more important that the Government should secure for British users of petrol a reasonable price than that it should participate as a shareholder in a company in excessive profits made at the expense of the British public." He did not

think the British public realised what those excess profits came to; they were about 40 per cent., he thought it was, on the income-tax. If the country ever did suffer from a shortage of petrol, he was quite sure the people would hold the Government responsible for not arriving at some solution of the question which ensured an adequate supply both in peace and war at a reasonable price. He did not think any hypothetical suggestions or guessings at future possibilities would ever solve the problem or produce the oil required. The simple-minded people of Great Britain and its Empire were being educated to believe that there would be no more wars, but only arbitrations through the League of Nations. It had been suggested that the League of Nations should regulate oil prices from an International point of view, but it was difficult to see how that could be carried out, in view of the fact that America, one of the biggest suppliers, was not a member of the League of Nations. Even now the Government was hesitating as to the adoption of some form of nationalisation of some of the country's resources, and it looked as though some people thought it was possible to internationalise them. As a matter of fact he understood that America expected very shortly not to be able to export any oil. Where, then, would this country have to look for its oil supplies? It was a very serious outlook, because our mechanical transport and our ships would not be mobile in time of war if supplies were not forthcoming.

In conclusion, he desired to thank the President very much for the honour he had done him in asking him to respond to the toast. He only desired in conclusion to express once more the thanks of the Army to all the Oil Companies for the great help they rendered during the war, particularly the great group to which he had already referred. After all, he did not think that he could pay a bigger tribute to the Managing Director than the late First Lord of the Admiralty did when he put a seal on his fame by dubbing him "The Napoleon of the Oil World." (Cheers.)

Brigadier-General R. K. Bagnall-Wild, C.M.G., thanked the President for the very great honour which had been accorded to him by asking him to respond to the toast on behalf of the Air Force. He had always heard that the next war would begin in the air before war was declared. That, of course, was Irish, but it was quite true, and it was necessary to think what it really meant. The Royal Air Force primarily consisted of pilots, but they were of no use without machines; the machines were of no use without engines, and the engines were of no use without lubricants and fuel. The Royal Air Force depended very largely on the

scientists and engineers of the country, especially in regard to fuels. The Royal Air Force was spoiled by being given aviation spirit. The Companies then knocked the bottom out of that by taking out the aromatic hydro-carbons ; then they were given 20 per cent. benzol, which was very nice, and they got on fairly well. If the Royal Air Force was brought down within very small limits the question had to be considered of what would happen when the next war occurred and it was necessary to increase the number of craft and all the accessories required. It was desirable to develop commercial aircraft. The Air Ministry were supervising civil aircraft, but they were not experimenting in it, and it was therefore necessary to ask for the help of the scientists in the outside world. A great help should be obtainable from the internal combustion engine expert in connection with civil aviation, particularly if it was possible to make a 6-cylinder engine with 1,200 revolutions a minute which burned heavy oil ; or it might be possible to go as far as the semi-Diesel type. It was on those types of engine that the commercial future of aviation depended, because it could not afford the luxury of aviation spirit which was used during the war. He must seriously ask scientists to turn their attention to that branch of the problem. (Cheers.)

"THE PETROLEUM INDUSTRY."

The President, in proposing the toast of "The Petroleum Industry," said he was not connected with the Admiralty for 37 years without learning something of the elements of naval strategy, although that was not his particular Department, and he did carry away from the Admiralty at least the elementary idea that the battleship, the battle-cruiser and the destroyer had their respective functions, while the humble supply ship kept somewhere in the rear. When he was asked to draw up the programme of toasts for that evening he carefully placed himself low down on the list in order that he might be able to say that the first Lord of the Admiralty and other distinguished speakers had already said all that it was possible to say about the petroleum industry. The industry that evening was amongst its friends. They had heard what it did during the war, how indispensable it was, and they had also heard how it was facing the problems that followed the war. There was only one thing he desired to mention which he thought had not been sufficiently emphasised already, and it dealt with the subject of economy. He heard a good story recently at a luncheon of engineers about the wonderful things that engineers could do. He

believed that when engineers went out into the wilderness the roses blossomed around them and civilisation immediately followed. A distinguished engineer once found himself in the other world; he did not find himself in the place allotted to the saints but he found himself among his old friends down below. He at once said: "Well, after all, this is not such a bad place; it is not nearly so black as I thought it would be," and his old friends replied: "But you ought to have known it before we came here." (Laughter.) If engineers could transform the inferno into the paradise he hoped they would not reserve all their energies for the future world, but would supply a few trifles also that were wanted in this world, particularly improvements in engines that would enable one gallon of petrol to do duty for two gallons and one ton of heavy oil to do duty for two tons. Had time permitted he would have given some ideas as to the lines upon which he thought something might be done, but he would reserve that for future meetings of the Institution. It was a particular pleasure to him to couple the name of Sir Marcus Samuel with the toast, and he hoped it would not be taken as evidence of the existence of a petrol ring if he referred to him as an old friend, because in the early days of oil fuel in the Navy he had many conversations with him, and he never talked to him without learning something helpful that he could put before the Board of Admiralty. Not only did he talk to Sir Marcus but he used to read his speeches to his shareholders, and he always regretted that his official position prevented him from having shares in some of his Oil Companies, because he would have done very well if he had. He had to give the whole benefit of that to the Navy. The first time he talked to Sir Marcus he explained to him the advantages of oil fuel in ships. Sir Marcus was one of the pioneers in using oil on board ship. He had great faith in it and had never ceased to preach its merits. The last time he had the opportunity of speaking to Sir Marcus he was telling him of another use for oil. Sir Marcus said that he had noticed that his (the President's) hair had grown a little white and thin in the service of the country, and he had promised him that as soon as his Borneo hair oil came on the market to provide him with a new head of hair. (Laughter.) He asked Sir Marcus to hurry up because otherwise a Persian brand or a Mexican brand would get in "ahead" of him. Sir Marcus asked him what he was going to say that evening and he replied "Nothing controversial," to which Sir Marcus made answer, "I am very sure of that." He most heartily commended to those present the toast of "The Petroleum Industry," which, before the war and during the war, had rendered

indispensable service, and was going on to face the problems in the future in the same way that it had faced them in the past. (Cheers).

Sir Marcus Samuel, Bart., in responding, said it gave him the utmost pleasure to reciprocate the kind expressions that had been uttered by his friend Sir Frederick Black. In the past they had had little differences, but he was quite certain that they always respected one another's motives, and he was glad to know that they were now working upon amicable terms. He desired to refer to a few of the remarks that had been made by the previous speakers. His friend, Sir Charles Greenway, had mentioned his experience on the banks of the Irawadi. He could not tell Sir Charles how much he wished he had been there, because he would have been able to assure him that his fears were unfounded, and that he need not have gone to Lord Curzon like a naughty little boy and said: "There is some big bully there who is coming out to give me a whack on the head; please protect me." The Company with which he was connected had worked on somewhat different lines. The Burmah Oil Company found it necessary to ask for Government protection, and it received subsidies. Subsequently when they embarked upon the Anglo-Persian venture they again went to the Government and said: "Give us a few millions to bring this thing to fruition." He envied Sir Charles the help that he obtained. Personally he had frequently applied to the Government for support but never once for financial help. That was where their two schools differed. Personally he believed that the great industry they represented would be built up by individual energy and enterprise, and that the less Government support there was, financially or by management, the more successful would the industry be. Sir Hamar Greenwood had referred to the question of prices. He could assure those present that the heads of the great petroleum Companies were as fully alive to the necessity of making good their case for advances in price as they could possibly be. He realised, as all realised, that in times of public passion and public temper, even when legitimately aroused, there was a danger, and he was glad to assure the gathering that the accusations that had been made had no foundation whatever in fact. When a man was charged with committing an offence it was one of the good habits of public life that he was warned. He was told: "You are not obliged to say anything, but whatever you do say may be taken down and used as evidence against you." That was a salutary plan in public life—that if men were attacked they could question the motives; they could question the truth of the statements made against them. They had entered on a most unfortunate period

when committees were appointed and could make accusations against individuals or groups without giving them the opportunity of cross-examining on the evidence upon which the accusations were based. It had been necessary to make a declaration—and he appealed to his many friends present, including Mr. Walter Long, and asked them whether they thought he would be a party to uttering an untruth—and he desired to repeat that declaration that there was no ring and no trust in the petroleum trade. The law of supply and demand was absolutely inexorable. A dangerous agitation had been started by the issue of a circular, which had been described by one of the best men in England, Mr. Alexander Wilson, as couched in terms so grotesque and ignorant that it could only serve to mislead the public. The petroleum Companies could take care of themselves, but he thought it was absolutely criminal to disseminate statements which could only arouse the animosity and greed of those who required a necessity of life at a price at which it was impossible to supply it. The report of the Petroleum Profiteering Committee had been described by one of our great newspapers as fatuous in its recommendations and futile in its suggestions, and therefore he did not think he need say anything more about it. He desired to say, however, that, if his Company had to supply petrol at the price that the committee laid down that it ought to be supplied at, there would be an actual loss of £1,600,000, and he did not think that any Company could possibly be expected to face such a loss. He was associated with Companies which produced by far the largest part of the profits of the Shell Company from oil raised in Sumatra and Java and sold in the East, and he did not think any fair-minded man could expect them out of profits derived elsewhere to subsidise the European trade, because that was what was suggested. It was not disputed or denied that those Companies made very large profits, but they were derived, not from trade in the United Kingdom or in Europe, but from the Far Eastern trade. He felt quite sure that when the public were informed of those facts and realised them quite a different feeling to that which now existed would prevail. He quite agreed that it was most desirable to secure supplies within the Empire. He had spent a life which was now drawing towards its close in an endeavour, which had not been altogether unsuccessful, to bring that about. His Company alone among all the oil Companies had developed supplies within the British Empire—he referred to Egypt, and more particularly to Sarawak, and they had done it without any Government assistance. He had often repeated, and he desired to repeat again, that all the resources of the Company with which he was connected had

always been willingly and gladly placed at the service of the Empire. It was no use crying at the moment if unfortunately there were no oil properties within the British Empire ; they should be extremely thankful that British enterprise had developed them elsewhere, and if British enterprise was backed up and not left in the lurch, as had repeatedly been the case, he did not at all despair of doing what was the next best thing to getting production within the Empire, namely, British control over the resources in other parts of the world which oil Companies had developed in such an extraordinary and successful fashion. It would be affectation on his part to say that the views he had just expressed were new to Mr. Walter Long and Sir Hamar Greenwood ; they were not ; but he had had the mortification several times of having overtures which had been made to the British Government, not to put money into the Shell Company but to give it their moral support, over and over again turned down ; he had failed to obtain that moral support. He hoped, however, that they were now entering on happier times. The war had revealed the marvellous assistance that petroleum Companies had been able to render to the nation, and he felt quite sure that, unless some extremely stupid measure was adopted—and he did not fear that now the Department had got into such good hands—supplies would not be alienated which were absolutely vital to the country, supplies particularly of the aviation spirit to which reference had been made. It was a very curious thing that petroleum differed as much in its constituent properties as individuals did in their different natures. The petroleums of Borneo and of Sumatra possessed attributes of their own which rendered them vital to the support of the industries of this country if it was to hold its own. The aviation spirit produced from Borneo oil contained enormous quantities of toluol and gave a greater power for aviation purposes than any other known spirit. He hoped Sir Charles Greenway would not mind him saying that Persian petrol was almost useless for aviation purposes. Why it was impossible to say. The boiling points apparently were all right, but in practice it could not be successfully used. The petrol of Sumatra was an extraordinary product, possessing powers which no other petrol had. He had been asked why he did not distribute in bulk. He did not think that would be a good thing for the petroleum industry generally, because if one particular kind was desired it was impossible to have it if it was all sold in bulk, and for that reason he did not think the suggestion that bulk oil should displace case oil distribution was possible. There was a saying that fools ventured to step in where angels feared to tread, and that

certainly applied to some of the advice that was tendered in regard to certain measures that had been taken. It was known probably to very few that the most tiresome factor to-day in the petroleum trade was the hopeless want of tonnage. Quite suddenly an amazing demand had arisen for liquid fuel, and it now took more tonnage to keep one country, Egypt, supplied with liquid fuel than was required for the entire trade of the Shell Company in petrol before the war. It was absolutely impossible for gentlemen who desired to give any advice upon the question of petroleum to base it on the knowledge of local trade in Great Britain. It was a large, complex and vexed subject, which required the knowledge of a lifetime. Dispositions of ships had to be varied not from day to day but from hour to hour, and to expect any man to sit down and make a report on the petrol trade from a purely insular point of view was absolute nonsense. He feared very much indeed that trouble might arise from representations which were no doubt well meant but which showed such colossal ignorance as to court disaster. He remembered a doctor who asked his patient in succession: "Do you eat well? Do you drink well? Do you sleep well?" and, receiving an affirmative answer to each question, the doctor replied: "I will give you something to take all that away." (Laughter.) That was what might follow if the advice of a well-meaning Committee was carried out. Up to the present at all events Great Britain had always had ample supplies of petroleum and of petrol at lower prices than any other country in Europe, and the recommendations of the Petrol Committee would be calculated if carried out to deprive her of those advantages. One of the recommendations was that the re-export of petrol was not to be permitted. The consequence of that would be that Great Britain would be merely supplied from hand to mouth. Rotterdam was most favourably situated as a port, from which the Rhine, Belgium, Holland, the north of France and the east coast of England could easily be supplied, and he thought it was very dangerous to attempt in that way a solution of a difficulty which had been brought about solely from natural causes. If the petroleum Companies wanted to hold their trade in Great Britain there was only one way in which they could do it, and he asked those present to accept it from him as a fact, namely, that they were willing to accept for their product a lower price than anybody else would supply the article for. There were a great many Companies outside the Standard Oil Company and the Royal Dutch group, and they would tell those present that they were not prepared to supply anything to Great Britain, for the reason that they would

do very much better by not shipping it at all. He thought those factors must be recognised and realised. He did not like to sit down without referring to the great services which had been rendered to the industry by Mr. Walter Long and Sir John Cadman, because the one essential for the successful conduct of the petroleum business of Great Britain was that those who were engaged in it should feel that they were dealing with gentlemen from whom they would receive fair play. If that principle was now established they would go a very long way towards securing that those services which had been hitherto rendered to the British Empire would continue to be rendered in the future, and he could not imagine any men more qualified to inspire that confidence than Mr. Walter Long and Sir John Cadman. It was undoubtedly true at the present moment that there were not enough supplies to go round, and therefore there was great necessity to develop other sources of supply. It might be of interest if he said, however, that he was extremely optimistic as to the future. He believed the present was only a passing phase. There were many countries which could and would supply petrol which were still undeveloped, in which refineries were not erected but in which there was production, and others in which there was huge production but it was impossible to export it. He referred to Russia and Rumania. He did not at all despair that in course of time the supply would overtake the demand, provided those who were qualified to deal with the matter were left alone and were helped and not hindered. He desired in conclusion to refer to the endowment which the great oil Companies, assisted by that great Englishman, Lord Cowdray, had given to Cambridge University. The gift was made with no selfish ends in view. It was no part of the idea of the petroleum Companies who made the gift that the University should devote the whole of the research to petroleum. They were perfectly free to devote the wonderful brains which they possessed in Sir William Pope, one of the greatest scientists of the day, to whatever purpose they pleased, but nothing would afford them greater pleasure than that their efforts should result in finding some substitute or some supplementary article to petroleum. He could not say whether that was practicable or not, but the matter certainly could not be in better hands than those of the great University. If Mr. Clive Pearson, who was present, liked to open his heart and say something about the anxieties and cares that beset Lord Cowdray before he reached success in Mexico, he would have a wonderful story to tell. Paraphrasing the words of Queen Mary, who said that "Calais" would be found on her heart, he believed that "Koetei" would be found on his. The terrible

anxieties connected with the production of oil were only known to those who endured them. They were twitted on making large profits, but people forgot the awful risks they ran. For every successful Company there were at least a hundred which never reached the dividend-paying stage at all. Personally he had been very successful, but if it were put to him whether he would again go through the anxieties that he endured in connection with the production of oil first of all in Borneo and secondly in Egypt, where at one time he feared that every shilling of the large amount of capital invested in the Company would be lost, he would reply that even if the reward was ten times as great as it was at present he would not go through them again. (Cheers.)

Sir Charles Greenway, Bart., thought it would be unfortunate if those present went away from the meeting under a wrong impression, and he therefore desired to assure Sir Marcus Samuel that the audience that took place on the banks of the Irawadi, to which he had previously referred, had no reference at all to Sir Marcus's Company; in fact, his Company's name was never mentioned at all in his discussions with the Indian Government.

"THE INSTITUTION OF PETROLEUM TECHNOLOGISTS."

The Hon. Clive Pearson, in proposing the toast of "The Institution of Petroleum Technologists," said that when he completed his notes for his speech that evening he was frightened that they would not fill up the time, but that anxiety was past and he would spare the members his speech altogether. Sir John Cadman, whose name he coupled with the toast, had a pet which he wished to put forward. There was a great opportunity at the present time for the industry to make rapid strides in its scientific development. It could not stand still; it must go rapidly forward. The Institution was alive and it wanted the support of the industry, not merely by the attendance of people at its dinners, but by real active support. He hoped the Institution would get busy in helping forward the training of the many men who were required in the technical branches of the industry, and he trusted that the Institution would get the support it deserved in that respect. (Cheers.)

Sir John Cadman, K.C.M.G., D.Sc., in responding, said he felt a touch of sadness in rising as the Senior Past President of the Institution because he realised that during the past year the Institution had lost its founder, who was a most distinguished man of science, namely, Sir Boverton Redwood. It was now six years since the Institution had its birth. At the moment everything

seemed open to it, because the war was not then upon the country. Since then the Institution had passed through a most perilous time, but even in its adversity it had progressed in a manner which spoke volumes for it. There were now 287 members of the Institution and throughout the whole of the war the Institution had never failed to meet at its ordinary meetings and discuss scientific questions which were of great moment. The work of the Institution was to encourage the scientific side of the profession, and it was a great tribute to the Institution to have present at the dinner, not only the Ministers who were now in charge of the Petroleum Department, but also the heads of the great industry. The Institution had to tackle the scientific side of the work. It did that among its members by disseminating knowledge and by reading and discussing papers. It also attempted to stimulate education and the training of men to take part in the work. It was a most extraordinary thing that in the development of the oil resources of the Empire it was necessary largely to rely upon foreigners. A few years ago an attempt was made to set in motion a process which took a generation to really bear fruit—an educational scheme which would put the boots under those who were ultimately to take charge of the industry. It was one of the tragedies of the war that some of the men who came forward for that training made the supreme sacrifice. It was his privilege to have charge of the Department which contained some of the budding youths of this country, and it was one of the most painful things to realise that some of those fellows who would at the present time but for the war have occupied junior positions were now no more. Although the period had been short there were men who were to-day doing work in those fields and who possessed those British characteristics which were necessary for the development of the Empire's resources. Some time ago Birmingham started the first scheme for education in any University in the world. That was followed rapidly by the Imperial College, the work there being in charge of Professor Watts who was present at the dinner. In the speeches that had been made the fact had been emphasised that it was necessary to make progress. Fields required testing and drilling and it was a lamentable fact that the great oil Companies had largely to depend on foreigners for that particular class of work. At the last dinner, the President, Sir Charles Greenway, referred to the necessity for the development of a scheme of that character, and he was happy to say that point had not been lost sight of. A scheme had now been developed which bade fair to provide a training for Britishers as drillers who would be able to supply the demands of the Com-

panies. He was permitted to state that his University was prepared to proceed on lines which he thought would materially assist in that direction. Up to the moment that particular work had been done without any financial assistance from any side whatever, but, thanks to the generosity of some of the great Companies and people interested in the movement, he was also able to state that very substantial assistance would be given to the movement. It was a movement which the country required, because unless it was able to train Britishers to-day to do the work it was absolutely hopeless to attempt to bring about the ideals that had been suggested. The hour was so late that it was impossible for him to say in detail what the scheme was, but, roughly, it consisted in erecting in this country four or five rigs with qualified trainers for the purpose of teaching men how to undertake the work. If that was given the full support it deserved he was sure it would not be long before Britishers were occupying the positions which to-day were filled by foreigners. He thanked those present for the hearty way in which the health of the Institution had been drunk. The Institution meant to progress; it had only just started, it was young and it did not intend to stop to think of the limits of its usefulness (Cheers.)

"THE GUESTS."

Professor J. S. S. Brame said it was a very great pleasure to him to propose the toast of "The Guests," among whom were many distinguished officers of the Navy and Army. The toast was coupled, however, with the name of Sir Arthur Duckham who, as the Director of Aircraft Production, did wonderful work for the country throughout the war. Among other guests the names of Sir Marcus Samuel and the Hon. Clive Pearson were familiar throughout the world for their association with the great petroleum Companies. He most heartily welcomed those gentlemen as guests, and he thought he was expressing the views of his fellow members of the Institution in hoping that at no distant date they might welcome them as members of the Institution. (Cheers.) Mr. Walter Long had referred to the way in which Englishmen were very slow in adopting new ideas, but nevertheless they sooner or later came along and generally passed the winning post ahead of their opponents. That was certainly the case in connection with aircraft. This country started behind other people, but through our energy, ability and business aptitude we finished strongly in front. During the war enormous reserves of machines were produced; the wastage, which was very great, was easily

replaced, while the supply of spare parts required for the machines was readily maintained. To no one did this country owe a deeper debt of gratitude than to Sir Arthur Duckham, who as Director of Aircraft Production was responsible for the wonderful recovery which this country made so far as aircraft was concerned. The Institution also had another claim upon Sir Arthur Duckham, whose inventive genius and ability had been associated with the coal tar distillation industry—an industry closely allied to petroleum technology. He was sure it was the feeling of most of the members of the Institution that that industry would in the future be more closely allied to the Institution. There had been some suspicion and probably antagonism in the past between coal tar products and petroleum products but there was room for both; and he hoped at an early date Sir Arthur Duckham would be welcomed at one of the meetings of the Institution and give useful information in his possession relating to the very important question of the distillation of coal. He asked the members to drink to the health of their guests, coupled with the name of Sir Arthur Duckham. (Cheers.)

Sir Arthur Duckham, K.C.B., said it was a very great honour and pleasure to him to respond to the toast on behalf of the guests. He appreciated perhaps as much as anyone did the usefulness of oil during the war, because not only was he responsible for aircraft but also for tanks, mechanical transport, agricultural machinery and tools and the electrical supply of Great Britain. Through the use which was made of oil it was possible to create a series of vast monsters, one of which contained eight 600 horse-power engines, a total of 4,800 horse-power in a comparatively small space. By means of oil it was possible to create a great leviathan of the sea and the great swarms of mechanical animals which ran along the roads of the country. The urgent question at the moment was how to meet the increasing demand for oil for the many uses to which it was put. Conditions in many cases made the use of solid fuel entirely prohibitive, and more and more it was necessary to use either oil or a gaseous product for the needs of the country. He strongly held the opinion that the Institution should keep closely in touch with the great problem of obtaining fuel oils and motor spirit from coal, which existed in large quantities in this country. He believed the Institution should use its great knowledge with the object of making a closer study of the production of oil from coal. If coal was handled properly there was no reason why that should not be done. The President had asked him if he would be prepared to read a paper to the Institution on the subject. His

technical knowledge was very limited ; he guessed a lot and pushed along in that way ; but any knowledge he possessed was absolutely at the disposal of the Institution, and he would be very pleased indeed to address the members on the subject, leaving them to deal with the matter from the technical point of view. On behalf of the guests, he again thanked the members for the cordial manner in which their health had been drunk.

The proceedings then terminated.

Forty-Second General Meeting.

This Meeting was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday, 16th December, 1919, Sir Frederick W. Black, K.C.B. (President) occupying the Chair.

The Members of Council present were Messrs. E. H. Cunningham Craig, Arthur W. Eastlake, James Kewley, Dr. W. R. Ormandy and Mr. Robert Redwood.

Letters of regret for unavoidable absence were received from Mr. H. Barringer, Sir John Cadman, Mr. T. C. Palmer and Dr. F. Mollwo Perkin.

The President, in opening the meeting, said he desired to announce that the Institution had been getting in touch with kindred Institutions, and had proposed an interchange of hospitality when papers of interest given at one Institution might be of interest to the other. The Institution of Automobile Engineers had informed them that a paper would be given at a meeting of that Institution to be held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on the 7th January, 1920, at 8 p.m., by Mr. D. J. Smith, on "Producer Gas for Motor-Vehicles," and any members of the Institution who desired to be present would only have to sign the book in the entrance-hall to be admitted to the meeting. The Institution of Automobile Engineers would extend the same courtesy of announcement of papers read before this Institution that might be of interest to Petroleum Technologists, and the latter would be glad to welcome at their meetings the members of the Institution of Automobile Engineers.

The following paper was then read, well illustrated by lantern slides :—

The Application of Liquid Fuel to Heavy-oil Engines.

By A. J. Wilson, A.M.I.M.E., *Member.*

In approaching this subject, the author feels that so much has already been contributed to the proceedings of the various Societies, and that so many admirable technical books have been published in recent years that there is not very much more to be said on this matter that is really new, however differently it may be expressed.

There is, however, an aspect of the case which may justify the reading of this paper, and that lies in the collation of scattered data and the presenting of the same in a connected form, with a view to promoting a useful discussion among the members of this Institution.

In view of the wide scope which a treatise on this subject provides, it may be advisable to begin with some definition of what is meant by the term "heavy-oil engine," and what is included in the phrase "liquid fuel."

A heavy-oil engine is for the purposes of the present paper considered to belong to one or other of the two classes (1) Diesel, or constant-pressure engines, in which the heat of compression alone fires the injected fuel, and (2) semi-Diesel, or constant-volume engines, in which ignition is obtained by the combined effect of compression and the surface-heat of a vaporising chamber.

This latter type has very many varieties, some of which are practically Diesel engines, but are difficult to classify as such, and for the present the author prefers to restrict the meaning of the term "semi-Diesel" to the definition laid down by the Diesel Engine Users Association.

Definition of a semi-Diesel Engine.—"A semi-Diesel engine is a prime mover actuated by the gases resulting from the combustion of a liquid fuel. A charge of oil is injected in the form of a spray into a combustion-space open to the cylinder of the engine at or about the time of maximum compression in the cylinder. The heat derived from an uncooled portion of the combustion-chamber, together with the heat generated by the compression of air to a moderate temperature, ignites the charge. The combustion of the charge takes place at, or approximately at, constant volume."

The liquid fuels for the engines mentioned in these two groups

may be derived from either petroleum or coal tar, and fall into the following classification :—

(1) Crude petroleum,
(2) Residual petroleum,
(3) Gas, or solar oil,
(4) Shale-oil,
(5) Creosote oil,
(6) Lignite-oil.

A consideration of methods for the use in internal-combustion engines of the lighter distillates of any of these fuels does not come within the scope of this paper.

Proceeding to a consideration of the Diesel types of engine and their fuel-injection systems, one is struck by the many different ways employed for achieving the same object, namely, the admission of the fuel in as finely a divided state as possible against the compression obtaining in the cylinder-combustion space.

These various methods may be broadly divided into two classes : (1) air blast-injection systems, and (2) solid or mechanical injection systems.

Air-Blast System.—This system is the more generally used in Diesel engines, and while giving satisfactory atomisation and turbulence, has the outstanding defect that the actual running of the engine is dependent upon the services of an air-compressor. The latter system, on the other hand, is quite independent of an air-compressor in so far as the running of the engine is concerned, although it should be borne in mind that the need of an air-compressor still exists, as the engine requires compressed air for starting and manœuvring purposes. The air-compressor of a solid injection engine has not, however, to provide for higher pressures than about 550 to 600 lbs., as against the 1,000 lbs. per sq. in. usual in the other system of fuel-injection. The solid-injection system possesses a slight advantage here, as the continuous running of the air-compressor is not essential, and since the majority of the troubles with air-compressors arise when on continuous service at high pressures, a corresponding immunity from breakdown should be obtained.

Ideal injection is not easy to achieve with either of these systems, owing to a number of complex circumstances. The flat-topped indicator-diagram associated with the theory of the constant-pressure cycle which Diesel strove to attain would involve a rate of injection proportional to the piston-speed under all conditions of load and engine-speed. Such an ideal as this is difficult to attain in practice, and the theoretical flat-topped card is more generally approximated by the diagram given in fig. 6.

Two conditions, which can hardly be dissociated, are essential to efficient fuel-injection, and these are atomisation and turbulence. Both are present in every system of injection, but in very varying proportions, and it may be said here that the air-blast system provides excellent turbulence, or swirling, of the atomised fuel during combustion with the heated air present in the cylinder at the completion of the compression-stroke. It can be shown that very efficient atomisation is obtainable with the high fluid-pressures used in the solid-injection system, but since no blast of air follows the fuel, and mixes the charge with the air compressed in the combustion-space, it seems fairly obvious that perfect combustion will not be so readily obtained with the heavier and more viscous fuel oils as would be the case with the blast system of injection.

As a set-off, however, to the advantages claimed by the adherents of the air-blast injection-method, there is the indisputable fact that in this system the entry of the compressed air lowers the tempera-

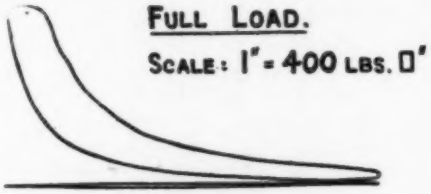

FIG. 6.

ture in the immediate vicinity of admission, owing to its expansion, and this at the precise moment when it is least desirable. This loss of heat would appear to be countered by the higher initial compression generally provided in the air-blast injection types of engine than is the case in the solid-injection engine. A pressure of 480 lbs. per sq. in. is usual in the former type, as against 430 lbs. in the latter, comparing engines of approximately the same cylinder-dimensions and power.

Proceeding now to a consideration of the many types of fuel-valve and pulverisers employed for injecting the oil in the Diesel type of engine, the diagram shown in fig. 7 indicates the standard design of several well-known makers. The valve itself consists of a long spindle, with a conical termination at one end, and a guide-sleeve at the other. The valve is arranged to open upwards, through the intermediary of a suitable lever operated by a cam, and is spring-loaded. It is the lower end of the fuel-valve and its casing that provides the most interesting features, inasmuch as it represents

the outcome of many years' experience in Diesel-engine construction. Surrounding the fuel-valve is a sheath, in which the spindle is guided. This sheath carries at its lower end a series of rings or discs, kept apart by distance-pieces, and in these rings a number of small holes are drilled. At the extreme end of the pulveriser-sheath is a nut of conical form, slotted on the outer face with equally-spaced tapering grooves. This "atomising" cone leads the fuel down to the spraying point or flame-plate, which in the figure is of the single-hole type. The fuel enters the casing at a point just above the top pulveriser-ring, and the amount depends upon the action of the governor which controls the fuel-pump. Compressed air is admitted near the top of the casing, the air being always above the fuel to be injected.

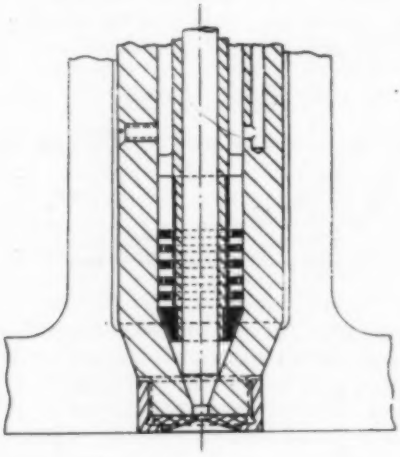

FIG. 7.

With this type of fuel-valve, the lift is constant, but the atomisation is not, as there is a tendency for the fuel, when a full charge is present, to get down as near as possible to the valve-seat, resulting in the first part of the injection being blown into the combustion-space in streaks, and not in the fine cloud which characterises the remainder of the charge.

The rate of injection when the load on the engine requires a lower M.E.P. is modified by lowering the blast-pressure to suit the reduced load. If the pressure were to remain the same when the amount of fuel to be injected is small, the effect would be for the blast air

to enter first, bringing the fuel after it at a much higher rate than the normal, causing violent "bumping" in the cylinders. These conditions apply to engines in which a constant speed is maintained by means of governing the delivery from the fuel-pump, and where the fuel-valve lift is constant, but the load variable.

To overcome the defects arising from these conditions, two main courses of action are allowable.

The methods adopted for dealing with ignition-troubles of this nature depend almost entirely upon whether a constant or a variable pressure of air-injection is employed. If the constant system is used, then a variable resistance in the pulveriser system will rectify the defect, and very many ingenious mechanical contrivances have been produced for providing variable resistance to the blast air.

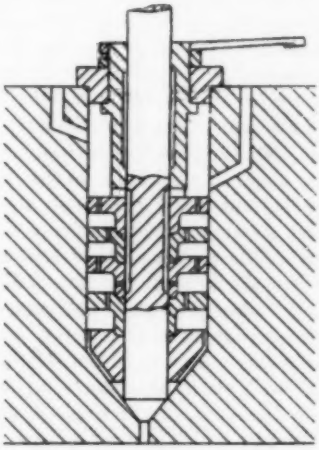

Fig. 8.

On the other hand, the variable blast-pressure system has much to recommend it, as it does not add complications to the fuel-valve design, which is already a rather intricate and expensive article to make, and is dependent upon very fine adjustments.

Dealing with the variable-resistance systems first, the illustration given in fig. 8 shows one of the Pasel designs for cutting out three-quarters of the pulveriser-rings, and giving the fuel a less tortuous path. A groove is cut in the valve-spindle down to the level of the bottom pulveriser-ring, and the entry to this groove or channel at the upper end is blanked by a sleeve having two ports opposite to

one another, and coinciding with the groove in the valve-spindle. This sleeve is operated from the outside, and can be turned so as to close the aperture as may be required.

Very many other equally ingenious devices have been brought forward by Continental engineers for attaining the same object as the example shown in fig. 8, but one of the British manufacturers, Messrs. Mirrlees, Bickerton & Day, have patented an apparatus for automatically controlling the blast air-pressure to an amount proportional to the load, which, in the author's opinion, is the preferable course to adopt. This arrangement consists of an electrically-operated control of the air passing to the L.P. stage of the compressor, and fig. 9 shows a diagrammatic arrangement of the apparatus.

It will be noted that the system shown in this diagram is applicable only to Diesel generating-sets, but engines for purposes of electric-generation are usually of the type having a constant speed, a constant fuel-valve lift and a governor-controlled charge of fuel: this apparatus for automatically varying the blast pressure to suit fluctuating load-conditions is particularly suitable.

The main current from the generator is passed round the solenoid A, and operates the finger B, precisely as in the case of an ammeter controlled by the current passing through the ammeter. The finger B swings over a scale marked in units of air-pressure, and is calibrated to point to the particular blast-pressure which is most suited to the engine at the moment, the zero position for this finger being the " no-load " blast-pressure. The pressure-gauge is connected to the pipe carrying the blast-injection air and the finger C registers whatever pressure may be in the blast-air system. Both fingers are provided with platinum contacts, and are insulated from one another. They therefore act as a single-pole switch, and make and break a relay circuit, which in due sequence makes and breaks the circuit which operates the throttle valve F on the L.P. suction inlet, the object of having a relay circuit being to avoid breaking a large current at the contact-points on the fingers B and C. The throttle-valve is held in its shut or normal position by the spring G.

Should the pressure in the blast-pipe become lower than is indicated by the finger B as the correct pressure for the load at which the engine may then be working, the fingers B and C would be apart, and consequently no current would be passing through the relay circuit, and the core J would rest on carbons K. Under such conditions the compressor throttle-valve circuit would be completed, and current would pass through the solenoid L, and the downward pull on the core which terminates in the throttle-valve

F would result in the free admission of air to the L.P. stage of the compressor.

Assuming the compressor to be of sufficient capacity, the blast-pressure would rapidly rise until the gauge-finger C again made contact with B, thus cutting out the throttle-valve circuit, and

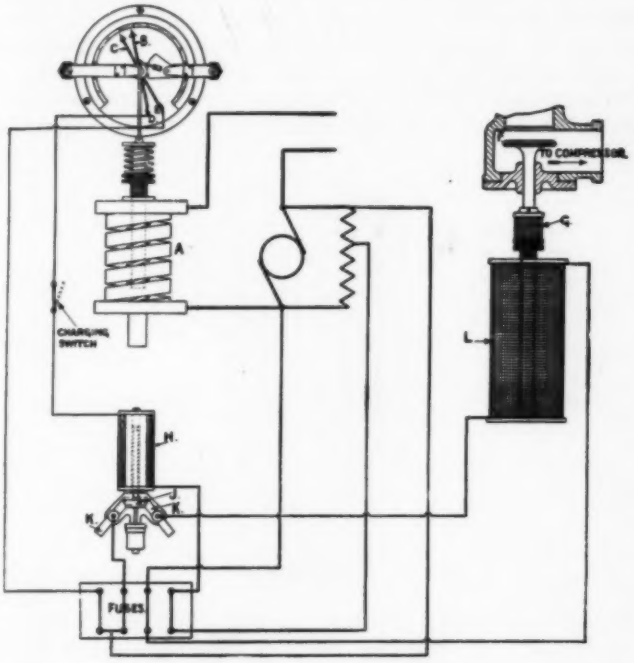

DIAGRAM OF CONNECTIONS FOR ELECTRICAL BLAST CONTROL GEAR. (SHOWING APPLICATION OF RELAY COIL)

FIG. 9.

causing the valve to shut through the action of the spring G. Matters would remain thus until a further variation in load took place.

This apparatus is exceedingly sensitive, and can deal with a

variation from 550 lbs. (no load) to 950 lbs. pressure (full load) in four seconds. This is rather quicker than the action of the governor, so the correct pressure is available when the altered fuel-charge comes along.

One of the pioneer firms among the Diesel engine manufacturers, namely, the Atlas Company of Stockholm, devoted a great deal of research to the problem of fuel-injection. They endeavoured to obtain the maximum amount of spread and atomisation with the minimum number of parts, and in the design of pulveriser shown in fig. 10 a result was achieved which met these requirements to an admirable degree, and at the same time proved to be almost

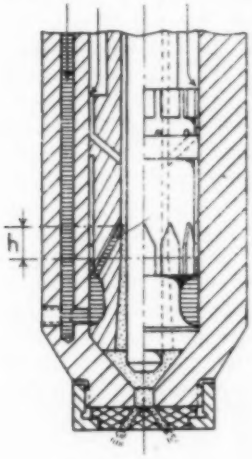

Fig. 10.

independent of variations in blast-pressure. The theory advanced by Mr. Hesselmann was that by having the air led down the centre of the injector or jet, the tendency due to inertia for the heavier particles of fuel to run together as a central stream surrounded by a mantle, or shroud, of rapidly-expanding air would be obviated, and that, in consequence, the atomised fuel would come into contact with hot air in the combustion-space more quickly. Whether this theory holds good or not, this valve certainly gives excellent atomisation and low fuel-consumptions in actual practice.

The characteristic feature of this valve is that instead of a series of perforated washers and a grooved terminal cone, the sleeve or pulveriser surrounds the valve-spindle with a considerable clearance,

which increases towards the bottom, and forms an injector through which the air-blast flows and expands. Fuel oil is led in the ordinary way to the bottom of the valve-casing, and enters an annular space, in which it rises to an extent depending upon the load demanded from the engine. Upon the valve lifting, the pressure in the injector is rapidly reduced, causing the oil to rise in the small oblique holes leading upward and inward from the annular space just referred to. The fuel passes down the injector, and is driven into the cylinder through a multi-hole flame-plate.

The drop in pressure in the injector will produce a certain head h (see diagram) measured from the oil-level in the annular space and that in the inclined holes. When the level of oil in this annular is lower by the head h, fuel ceases to pass into the injector.

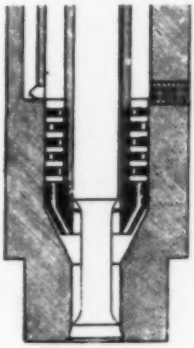

FIG. 11.

Before leaving the subject of Diesel-engine fuel-valves, mention should be made of the Burmeister & Wain design, fig. 11, which is remarkable in being the only Diesel fuel-valve opening inwards to the cylinder or combustion-space. The pulverisers are designed on much the same lines as those shown in fig. 7, but the fuel acquires a spinning motion by passing through spiral, or inclined, flutes in the conical nut, and the mushroom head to the valve greatly assists in spreading the fuel all over the top of the piston, instead of injecting it into the centre, where it is apt to cause excessive local heating. It will be noted that the valve has no flame-plate, in contrast to the type of valve shown in fig. 7.

Many other variations on these designs could be described, but perhaps sufficient have been shown to illustrate their general principles.

Solid-Injection Systems.—Apart from individual experimental engines, the only Diesel-type engine using the solid-injection system which has been manufactured in any quantity, is the Vickers submarine engine, with a maximum power per cylinder of 100 B.H.P.

The McKechnie-Vickers system of fuel-injection consists, briefly, of a high-pressure oil-pump supplying fuel to a main from which a definite amount can be admitted per firing-stroke to each cylinder by a mechanically-operated fuel-valve having a nozzle in which 5 or more very fine holes are drilled.

Control of the power is obtained by varying the time and the amount of opening of the fuel-valve, and by adjusting the pump to the desired pressure. Very perfect filtration of the fuel is needed owing to the fineness of the spray-holes in the nozzle referred to, these holes being only 0·017" or less in diameter. Refined shale-oil was generally used as a fuel, and the atomisation obtained was remarkably good, pump-pressures of 3000 lbs. to 3500 lbs. being employed for charging the fuel-rail or accumulator-system. Solid injection may be said to be the universal system employed by semi-Diesel engine manufacturers, with one or two notable exceptions, such as the Blackstone engine, which has a dual arrangement of fuel-injection, both using compressed air for injection.

Before passing on to a consideration of the numerous semi-Diesel types, attention is directed to a very interesting example of fusion between the Diesel engine proper and the high-compression semi-Diesel. This is the modified Doxford opposed-piston marine Diesel oil-engine which is now, as re-designed, no longer a true Diesel engine, and presents very unusual features. Briefly, this opposed-piston engine has revolutionised standard practice, inasmuch as the combustion space has no hot bulb, neither is the compression (800 lbs.) sufficient to ignite the oil unaided. Instead of a hot bulb, a hot piston-end is employed, which attains a temperature of about 1000° F. on full load, suitable means being provided for keeping the hot part of the piston from transferring its heat to the body of the piston and thence to the liner walls. Unlike any other engine, the " cooling " water is heated before starting up to ensure the necessary temperature of 140° F. being attained at the start. An injection-pressure of 8000 lbs. per sq. in. is employed, and two fuel-valves per cylinder are fitted opposite to one another, but at very slightly different levels, thus providing an unusual degree of turbulence without recourse to air-blast injection.

Although there are a number of semi-Diesel engines of the horizontal type manufactured by British firms, these nearly all work on the four-stroke cycle, and have compressions ranging

from 150 to 350 lbs. per sq. in. Space does not permit of all of these being described in detail, but the engine put on the market in 1914 by Messrs. Blackstone & Co., Ltd. and the one now offered by Messrs. Crossley Bros., are specially interesting.

In the case of the Blackstone engine we find a most ingenious compromise between the true Diesel air-injection engine and the solid-injection vaporiser type of semi-Diesel. Duplex injection is employed, blast-air at a pressure of 350 lbs. per sq. in. being taken to a pair of fuel-inlet valves, or atomisers, one of which opens with a slight lead on the other. The leading valve delivers a small charge of oil to a hot bulb, and maintains this, automatically and continuously, at the required temperature for igniting the main charge at all conditions of load. The jet of flame from this hot bulb is arranged to escape into the main cylinder through an orifice

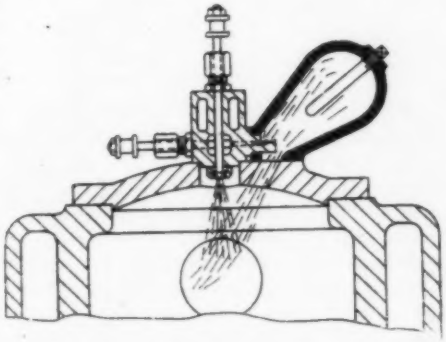

FIG. 12.

which deflects the flame obliquely into the spray from the main fuel valve, fig. 12, causing the charge to burn rather than explode. The initial compression in the main cylinder is only 150 lbs. per sq. in., and the engine might be described as a low-compression Diesel with pilot ignition, were it not that the ignition originates from the heat of a hot bulb, and not as a result of air-compression.

The new Crossley oil-engine marks a very great advance in oil-engine design, and challenges comparison with the true Diesel engine for fuel-economy and mechanical efficiency. Unlike the Blackstone engine, solid injection is employed, and the engine is started from cold with an initial compression of 260 lbs. per sq. in., paraffin oil being used to get away on.

The engine can be started on 150 lbs. pressure of compressed air

as against the 700 lbs. pressure generally used with Diesel engines, and the fuel consumptions are remarkably good, as the following figures from tests made by Prof. F. W. Burstall will show :—

Crossley Oil-engine : 18½″ bore × 28″ stroke.
Normal rated load : 117 B.H.P. @ 180 R.P.M.

Fuel.	B.H.P.	Oil used per B.H.P. hour.	Thermal Efficiency on B.H.P.
Residual ...	142·0	0·457 lb.	30·93%
Petroleum ...	125·0	0·425	33·26
18,000 ...	96·7	0·424	33·35
B.Th.U. ...	30·9	0·647	21·85
per lb. ...	0·0	11·0 lb. per hour	—
...	146·0	0·514*	30·22
Tar Oil ...	129·0	0·504	31·01
16,200 ...	102·0	0·475	32·84
B.Th.U. ...	67·0	0·488	31·26
per lb. ...	32·0	0·700	21·47
...	0·0	10·16 lb. per hour	—

* These figures include a small proportion of kerosene for ignition purposes.

These excellent results are largely attributable to the high degree of atomisation, and the efficient turbulence caused by the peculiar shape of the combustion-chamber and piston-head. Fig. 13 shows details of the "hot bulb," and indicate how turbulence, the one thing so far missing from most solid-injection systems, has been achieved.

A few brief notes on two-stroke vertical type semi-Diesel engines must bring the engine-section of this paper to a close, as neither space nor time permits of the subject being treated at all exhaustively.

The great majority of the vertical-type semi-Diesel engines operate on the two-stroke cycle, and although minor differences can be noted between competitive engines, they all follow more or less standard lines, as the sections through the Beardmore, Bolinder and Petter types illustrated in fig. 14 will show, and it will be seen that all these are of the hot-bulb type.

Solid injection is the general practice, and the efficiency of the engine's scavenging arrangements has an important bearing on the speed of ignition and the completeness or otherwise of the combustion.

Other considerations which have an important bearing on the matter are the distance through which the injected oil is thrown,

i.e. the length of travel from the injector-nozzle to the surface of the hot bulb, and the point in the cycle at which injection occurs.

Pressure of injection is rarely less than 2000 lbs. per sq. in. in engines of this type, and the initial compression in the main cylinders does not usually exceed 180 lbs. As in all solid-injection systems, the pressure of injection depends either upon the piston-speed of the fuel-pump itself, or upon the angle of revolution of the crank allowed for injection of the fuel. The size and number of the holes in the fuel-valve nozzle also influence the pressure. Injection should, of course, be as rapid as possible if "after-drip" is to be avoided, and combustion is helped if the complete charge can be injected into the bulb before any of the fuel actually reaches the heated walls of the bulb.

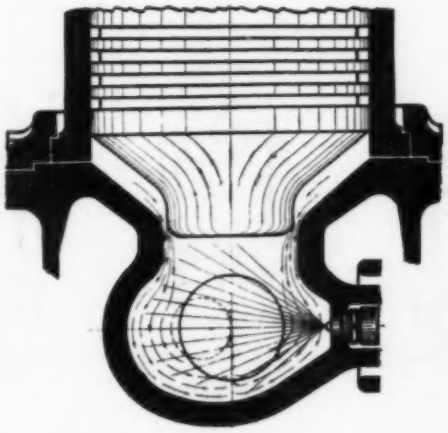

Fig. 18.

The relation of scavenging efficiency upon the combustion of the charge needs no explanation, and with these types of crank-chamber compression-engines, the amount of air available for scavenging per revolution depends on the volume swept by the working piston. Large exhaust-ports, ample passages, a large silencer arranged as closely as possible to the engine, and freedom from bends in the exhaust-pipes, all assist the maximum scavenging efficiency being obtained, which in its turn will give the best results in the combustion-chamber.

Fuels.—Turning now to a consideration of the liquid fuels, the term crude oil seems to have been somewhat loosely applied by those responsible for the sales literature of oil-engine manufacturing concerns. Crude oil as understood by the oil industry, is oil in the natural state, complete with all the lighter fractions present. In that state the flash-point is low, which may necessitate some re-adjustment of an engine designed and adjusted for running on residual petroleum. Water and sand may also be present in a greater or less degree, and while crude oil may certainly be used for oil-engines in localities where the oil is obtained in its natural state, or for marine-type Diesel-engines installed in ocean-going vessels, heavy-oil engines in this country are almost invariably run on residual fuels, or on gas oils.

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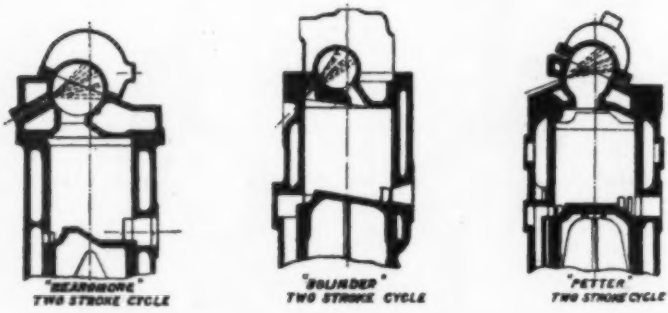


Fig. 14.

The residual fuel-oil (petroleum residuum) exhibits characteristic features according to the source of its origin, the Pennsylvanian or paraffin-base fuels being remarkable for their low gravity, low viscosity and low asphalt contents. At the other end of the scale are the Mexican residual oils with a high specific gravity, high viscosity and a large asphalt content.

The specific gravity has some bearing on the suitability or otherwise of a petroleum oil for Diesel-engine use, inasmuch as it would reveal, within limits, whether the oil was of asphaltic or paraffin base, and it would also indicate whether it was a distillate or not. It should also be borne in mind that high specific gravity generally accompanies a low calorific value, and it is also less easy to clear a

fuel of water when the specific gravity is approximately the same as water itself.

Viscosity has a direct influence on the thermal efficiency of the engine, as the more viscous the oil the lower the thermal efficiency will be. The probable cause of loss in thermal efficiency due to a viscous oil is the inferior degree of fineness of atomisation obtained. It may be assumed that the globules are larger, and it is known that large globules do not ignite with the same readiness as very small ones. In the case of a Diesel oil-engine this would result in delayed burning of the charge, and consequent loss of power on the expansion-part of the power-stroke, together with an excess of heat being lost by the exhaust as a consequence.

This falling off in thermal efficiency may be adjusted in several ways, the two most obvious being to preheat the oil before passing same to the engine fuel-pump, or to increase the blast pressure. Fitting a different type of pulveriser to the fuel valve may also overcome the difficulty.

Asphaltum-content in petroleum fuel oils is generally closely connected with viscosity, and the presence of asphalt is undesirable, as it will not distil, and forms coke when heated. This coke may attach itself to the exhaust-valve face, as it does not always burn quickly enough to complete the combustion of the charge before the valve opens. This incomplete combustion will explain the high exhaust temperatures of engines running on residual oils having a high asphalt content. Since coke will burn to ash, beyond which point combustion cannot be carried, it will be seen that the final residue, i.e. ash, is the most important factor in the choice of a Diesel-engine fuel, if freedom from exhaust-valve troubles and unburnt residue in the combustion-chamber is to be obtained.

At a casual glance a percentage of 0·10 of ash may not seem an undue amount to have in a Diesel-engine fuel, but although it is admittedly a very small percentage of the whole, the cumulative effect in an engine engaged on long non-stop runs becomes a serious matter to the engineer in charge. As an example, let us take the case of a 1000 B.H.P. engine driving a vessel, say, from a European port to the Far East. Taking a fuel-consumption of ·45 lb. per B.H.P. hour, the engine would consume about 100 tons of fuel in 21 days running, during which time no less than 2 cwt. of ash would have been either retained in pockets in the combustion-chamber or blown through into the exhaust system, where it would provide a potential if not an actual source of trouble.

Analyses of typical samples of fuel oil are given below :—

Paraffin-base fuel-oil (Anglo-American).

Specific gravity	·8887 @ 20° C.
Closed flash-point (Gray)	236° F.
Asphalt	1·54 %
Water	None.
Ash	Traces.
Sulphur	0·635 %
Hydrogen	12·55 %
Temp. of spontaneous ignition in oxygen (Moore)	269° C.
Gross calorific value	19,404 B.Th.U.
Net „ „	18,194 do.

Light asphalt-base fuel-oil (Anglo-Mexican).

Specific gravity	·910 @ 20° C.
Closed flash-point (Gray)	230° F.
Asphalt	8·0 %
Water	0·25 %
Coke	5·0 %
Ash	0·02 %
Sulphur	2·5 %
Temp. of spontaneous ignition in oxygen (Moore)	260° C.
Gross calorific value	19,200 B.Th.U.
Net „ „	18,034 do.

An ash-content of about 0·06 % is about the outside limit for a Diesel oil-engine petroleum-fuel, although slightly higher percentages are sometimes permissible in the case of tar-oils, the reason being that much of the ash may be of a soft nature, such as sodium sulphate, which results from the washing of the oil to remove tar acids.

Petroleum distillates, such as gas-oil, are particularly suitable fuels for the semi-Diesel class of engines, as these oils are, or should be free from water, ash and asphalt, besides having a high calorific value.

A fuel having a high coke-value is apt to cause a semi-Diesel engine to develop running-troubles, as in the great majority of designs more reliance is placed in the heat of the hot bulb for combustion than in the fineness of the atomisation and heat of compression.

As a guide to the temperatures obtained in the bulb the average conditions are these :—

Light load, with bulb just showing colour in the dark ; temperature about 750° F.

Normal load, bulb dull red : 1,000° F.

Overload : bulb bright cherry-red : 1,400° F.

It can be shown that a very fine degree of atomisation will enable a Diesel engine to use fuels having a comparatively high coke-value, as the coke is burnt to ash, owing to there being more oxygen present per unit of volume than in the case of a semi-Diesel engine, and yet the same fuel might rapidly choke up the combustion-space of a semi-Diesel engine with unburnt coke residue until the engine ceased to function correctly.

A typical analysis of a gas-oil is given below :—

Specific gravity	·850 @ 20° C.
Closed flash-point (Gray)	184° F.
Water	None.
Ash	None.
Coke	0·4 %
Sulphur	0·21 %
Hydrogen	12·8 %
Temp. of spontaneous ignition in oxygen (Moore)	254° C.
Gross calorific value	19,584 B.Th.U.
Net „ „	18,347 do.

Such an oil as this should present no difficulties in combustion for any of the semi-Diesel engines, although it would of course be unsuitable for engines fitted with vaporisers, a class which needs the paraffin fractions.

In case it may be contended that the hot bulb of a semi-Diesel engine acts also as a vaporiser, it may be as well to state here that the main difference between a four-cycle vaporiser engine and a hot bulb one is that in the former the fuel enters the cylinder in advance of the compression-stroke, while in the latter type the fuel is injected into the combustion-space under pressure towards the close of the compression-stroke.

Shale-oils as used in Diesel engines are generally the gas-oil fractions, and behave in much the same way as gas oils from crude petroleum. Being low in ignition-point, combustion in the case of a Diesel engine is rather too rapid, and there is a tendency for the engine to " bump " in engines using air-blast injection, unless special atomisers are fitted. As a fuel for the solid-injection type

of submarine Diesel engine, or high speed, it has given good results, and the following analysis may be of interest :—

Analysis of Gas Oil from Shale.

Specific gravity	·850 @ 20° C.
Closed flash point (Gray)	180° F.
Water	None.
Coke	0·5 %
Ash	None.
Sulphur	0·3 %
Temp. of spontaneous ignition in oxygen ...	252° C.
Gross calorific value	19,600 B.Th.U.
Net „ „	18,400 do.

The employment of tar-oils as a fuel for Diesel engines, owing to the scarcity of petroleum fuel-supplies, resulted in some modifications being made in the usual methods of fuel-injection, as the higher spontaneous-ignition temperature of tar-oil was a serious obstacle to its use at first. This will be appreciated when it is noted that whereas the spontaneous-ignition point of most petroleum-residual fuels (in oxygen) is about 270° C., it requires a temperature of 480° C. to cause a tar-oil to ignite in oxygen without the introduction of a flame or spark.

With regard to spontaneous-ignition tests being taken in oxygen, it is considered preferable to take such results as more comparable to conditions obtaining in a Diesel engine with a compression of about 30 atmospheres, than if the ignition-points were taken in air, the main circumstance affecting the ignition-point being the concentration of oxygen. (See H. Moore's paper on " Tar Oil for Diesel Engines," given before the Diesel Engine Users Association, May 26th, 1918.)

Since the oil in the case of a Diesel engine is ignited by the heat of the compression, the natural line of action when using tar-oil would seem to be clear enough, viz. : to increase the compression-ratio. To enable the engine to start from cold the compression of 480 lbs. (the average Diesel-engine figure) would need to be raised to 650 at least, which would consequently increase the working stresses in the engine to a most undesirable point.

The danger of breakdown associated with this method of attaining the desired temperature was too serious to allow the matter to rest there, so other means of using this fuel were investigated. These were as follows :—(1) running the engine hotter, and using a petroleum fuel to start on ; (2) mixing petroleum oil with the tar oil : no modification to the engine involved ; or (3) using a pilot-

charge of petroleum fuel with a special ignition-gear: this involves a mechanical alteration to the engine.

The first-named is not a desirable practice, but can be attained by heating (*a*) the blast air, (*b*) the suction air, or (*c*) the circulating water by restricting the amount passing.

There are some risks attending this method of utilising tar-oil, inasmuch as hot-blast air may cause an explosion in the fuel-valve casing. The effect of heating the fuel itself, and of raising the temperature of the circulating water is but slightly beneficial, and an adverse effect on the lubrication of the main cylinder may be expected with average qualities of lubricating oils, if the temperature of jacket-cooling water is allowed to rise too near boiling-point.

A compromise between these conflicting conditions would seem to have been attained by: (1) maintaining the compression up to original limit when a new engine; (2) advancing the point at which the fuel-valve opens from the usual 3° before top centre to 9°; (3) starting the engine on petroleum fuel; (4) running on petroleum fuel if the load falls to 0·5 or less; or (5) modifying the fuel-valve so that a small proportion of the tar-oil may enter in advance of the remainder.

The advancing of the point of injection proved very beneficial when running on tar-oil, the effect being to increase the length of time during which the oil would be subjected to the maximum heat. The slow ignition peculiar to aromatic compounds is to some extent counteracted by these means, and when it is borne in mind that the injection-period is only about 10 % of the power-stroke, and that this means complete combustion of the charge in approximately 0·015 of a second in engines operating at about 200 R.P.M., the value of early injection will be apparent. In the case of engines having non-water-cooled pistons, it is interesting to note the improved ignition obtained with the larger sizes of cylinder, which is probably due to the proportionately greater mass of heated metal in the vicinity of the fuel.

The second method has been exhaustively investigated by Rieppel, to whom much of the pioneer work in investigating the use of tar-oils in Diesel engines may be credited. In these experiments gas-oil was used in proportions varying from 10 % gas-oil and 90 % tar-oil, down to a mixture of 90 % gas-oil and 10 % tar-oil. The result of Rieppel's investigations showed that if good running on variable loads was required, 25 % tar-oil was the maximum amount permissible. Such a mixture as this would permit of an engine of normal Diesel compression starting from cold on the fuel, without involving any change-over to a second fuel.

The difference in the specific gravities of the two fuels would present difficulties in keeping them mixed, and mechanical stirring of the storage-tank would probably be necessary. In view of the small saving in using only 25 % tar-oil, coupled with the higher cost of gas-oil, it is doubtful whether the use of mixed fuels offers any appreciable advantage to the consumer.

The third, or pilot-ignition method, is perhaps the most satisfactory solution yet brought forward for meeting the difficulties attending the use of tar-oil as a fuel in Diesel engines, the only disadvantage arising from this method being the additional working parts involved, as two fuel-pumps are now required.

In using this system the engine is operating on two oils, each kept separate until they meet in the combustion-chamber. The petroleum fuel is referred to as "ignition" oil, its function being to precede the tar-oil, and by burning as soon as the fuel-valve lifts, it raises the temperature sufficiently to ignite the tar-oil.

The operation of this system is clear from the illustration given in fig. 15, which shows the method employed by Messrs. Mirrlees, Bickerton & Day.

Before leaving the subject of tar-oil, one almost universal trouble associated with its use may be referred to. This was the choking of the pulveriser with a more or less dense black deposit, rendering it necessary to withdraw the fuel-valves every 100 hours, or less, to clean them. The standard type of Diesel engine fuel-valve was designed to mix the air with petroleum fuel at the pulveriser rings, see fig. 7, the holes in the rings being so arranged as to ensure that air would pass through the fuel, and not merely round it. The flutes in the coned end of the atomiser have a tendency to cause the fuel to coalesce, and at low loads, with a corresponding lower blast pressure, this streakiness is more noticeable.

From the behaviour of the tar-oil it would seem that oxidation takes place in the standard type of valve, and accordingly a special type of fuel-valve, having what is known as a "sleeve pulveriser" was introduced by Mr. P. H. Smith. The chief point about this valve is that it delays mixing the fuel and the blast-air until just above the fuel-valve seat.

An illustration of the valve is given in fig. 16.

Fuel enters at A, and settles round the outside of the sleeve where it comes under the influence of the blast-air. When the valve opens, the pressure of this blast-air forces it down the outside of the sleeve, and past an annular restriction at D, with the result that the oil is reduced to a thin film. The full pressure of the blast-air issues from the holes C, and the oil passes out through the

fuel-valve orifice in a fine spray. Any coalescence is rectified by the action of the blast on the annular knife-edges of the flame-plate F, the charge finally passing out into the cylinder in a comparatively "dry" condition, i.e. in a state best calculated to produce ready ignition.

The accumulation of black deposit referred to is less pronounced with this type of fuel-valve, or, at any rate, it is not so objectionable as in the standard type of valve having pulveriser rings. One

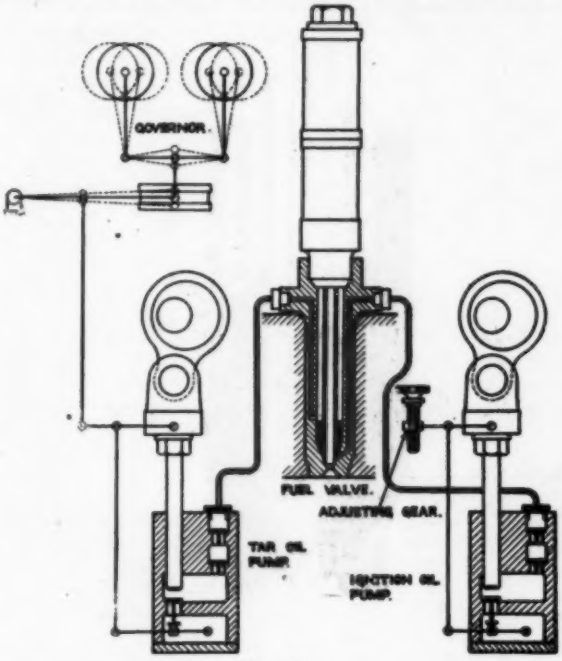


FIG. 15.

method of dealing with this choking difficulty is to run the engine for about 15 minutes on petroleum fuel every 5 or 6 hours. This clears out most of the deposit, and renders it possible to run for long periods on tar-oil without dismantling the fuel-valve any oftener than is usual with the petroleum fuel for inspection of the valve-face.

Some tar-oils are more apt to choke the fuel-valve pulverisers than others, and experience has shown that a good guide to the

suitability of a tar-oil fuel for Diesel-engine use is the percentage which is insoluble in xylol. This percentage would include the free carbon and any foreign matter picked up by the passage of the oil through the distilling plant, and it is interesting to note that the M.A.N. Company in their specification for tar-oil limited this insoluble matter to 0·2 %.

This question of what is, or what is not, a suitable tar-oil for Diesel-engine purposes has engaged the attention of the Diesel Engine Users Association for some years past, and has formed the

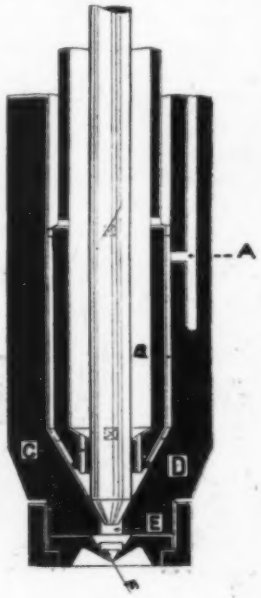


Fig. 16.

subject of a number of papers read before that Association's meetings. The specification used by the National Fuel Oil Company is as below :—

Specific gravity at 20° C.	Below	1·10
Flash point (open)	Above	150° F.
Coke	Below	3 %
Ash	„	0·05 %
Matter insoluble in benzine ...	„	0·25 %
Total water by volume	„	1·5 %
Separated water		Nil.

This represents a safe average class of fuel which experience has shown to give excellent results in practice.

Creosote oils, i.e. distillates of coal tar, vary considerably in their characteristics, the wide differences met with being primarily due to: (1) the kind of coal from which the tar was derived, and (2) the process and plant used in carbonisation of the coal.

The two chief sources of the tars are the gas industry and metallurgical coke-plants, or coke-ovens. On the one hand we have a product of coal carbonisation with the maximum production of illuminating gas as the main object, and on the other the chief aim is the production of a heavy coke or smokeless fuel. The tar is regarded merely as a by-product from these industries, and no particular pains are taken to produce either the maximum quantity, or to render it suitable for distillation as a fuel for Diesel engines.

Horizontal retorts are very largely used in the British gas-making industry, and do not produce so satisfactory a tar as the vertical retorts, from the point of view of distillation of suitable tar-oils for Diesel-engine use.

The tars from vertical retorts contain less free carbon, less naphthalene and rather more hydrogen. As a result the vertical-retort tars contain more aliphatic hydrocarbons, and combustion should therefore be easier than in the case where a large proportion of the hydrocarbons are of the aromatic or closed-chain structure.

The chief outstanding feature of the tar- or creosote-oils is their high spontaneous-ignition point compared with petroleum fuels, as the table given below will indicate (See H. Moore, *Journ. Soc. Chem. Ind.*, xxxvi, 109-112. 1917):—

Fuel.	Specific gravity.	Spont. ignition temp. In oxygen.	In air.
Crude petroleum (Texas) ...	0·936	268·5° C.	416° C.
Anglo-Mexican fuel-oil ...	0·908	259·5° C.	417° C.
Creosote oil (Hardman & Holden)	1·010	415° C.	—
Coke-oven tar-oil (Simon Carve's)	1·046	478° C.	—

A typical analysis of a horizontal-retort tar-oil is given herewith:

Specific gravity	1·049 @ 20° C.
Closed flash point (Gray)	200° F.
Water	0·60 %
Coke	None.
Ash	Traces.
Sulphur	0·68 %
Hydrogen	7·4 %
Tar acids	14 %
Gross calorific value	16,544 B.Th.U.
Net " "	15,868 do.

The author has not been able to secure for purposes of comparison any analysis of a vertical-retort tar-oil prepared from the same coal as the horizontal-retort tar-oil given above, but reference to the data given in Messrs. Constam & Schläpfer's paper would indicate that the claim made for the vertical retort can be substantiated.

Raw tars when heated can be used as a Diesel-engine fuel with some measure of success, but the chief trouble associated with the use of coal gas raw tars lies in the free carbon, the water and the ash-contents, and here again the vertical-retort tars have demonstrated their superiority. A free-carbon content of higher than 4 % begins to present difficulties, but 6 % may be taken as the limit for internal-combustion engine work, and since the horizontal-retort tars contain from 20 to 30 % of free carbon, the use of such tars is not practicable in a Diesel engine.

Tars and tar-oils distilled from lignite, however, present quite a different proposition, and this appears to have been very early recognised in Germany.

Lignite-tar distillates have a strong resemblance to those obtained from shale-oil and petroleum, as the accompanying analysis will show :—

Specific gravity	·880 @ 20° C.
Closed flash point (Gray)	230° F.
Water	None.
Coke	0·2 %
Ash	None.
Sulphur	0·6 %
Gross calorific value	19,180 B.Th.U.
Net „ „	18,000 do.

As may be expected with such an analysis as this, the lignite oils are perfectly satisfactory in any Diesel engine which will run on a petroleum gas-oil, and no special apparatus is required as in the case of coal-tar oils.

The vast extent of the lignite deposits in Germany can be gathered from the fact that in Saxony alone one million tons is retorted per annum, giving a yield of 60,000 tons of crude oil, having a specific gravity of 0·880 to 0·900.

In J. A. Greene's recent Treatise on British Mineral Oil, p. 162, the average yield of the Saxony lignite tars on distillation is given as follows :—

2 to 3%	benzine.
2 to 3%	solar oil.
10 to 12%	pale vaseline oil.
30 to 35%	gas-oil.

10 to 15% heavy-vaseline oil.
8 to 12% hard paraffin.
3 to 6% soft do.
4 to 6% pitch and coke.
20 to 25% loss.

The deposits of lignite in Great Britain as proved up to date are not very extensive, the best-known occurrence being at Bovey Tracey in Devonshire, where lignite was found as far back as the 18th century in certain pits opened up for working ball clay. Numerous bore-holes have of recent years been put down to prove the extent of the lignite-bearing clay beds, and the results are on record in vol. vii of the Special Memoirs of the Geological Survey on the Mineral Resources of Great Britain, part 1. 1918.

As might be expected, very little, if any, experience is available on the running of Diesel engines on crude lignite-tars obtained from our own natural resources, but according to German technical journals, it is quite possible to use these tars on Diesel engines without any modification in the standard types of engine, and no special fittings are required, except perhaps a pre-heater on account of paraffin-wax content.

The dependence of our national industries on a plentiful supply of cheap fuel has been painfully brought home to us during the present year, and it is to be hoped that the undeveloped resources of the shale fields in Norfolk, and such lignite deposits as we have in other parts of the country, will receive the attention that they merit in the coming year.

DISCUSSION.

The President, in proposing a hearty vote of thanks to the author for his paper, said the author had very correctly described it as a bringing together in concise form of scattered data, and if it had no other object than that it would be of very great value to the Institution. He hoped, however, it would give some of the younger members of the Institution, who often stated that the senior members monopolised all the time for discussion, an opportunity of airing their views. The paper divided itself into two parts—the engineering aspect and the oil aspect. Personally he approached the subject from the point of view of one who had been very much interested as a user or consumer, and more recently as a producer of oil.

In a paper recently read before the Institution, Admiral Dumas advocated the use of Diesel engines to a much greater extent in

ships of war, and a very high authority, Admiral Goodwin, pointed out that it was impossible to put, in a destroyer with 29,000 h.p., or a big cruiser with perhaps 140,000 h.p., Diesel engines of the weight that would be necessary to produce those powers. That in itself was obviously a very serious limitation for marine purposes of the use of the Diesel engine. It might perhaps be inferred from that statement that at any rate there might be a good prospect of installing Diesel engines in ships that had not to develop such high powers, such as the humble tramp steamers that went about the world on their useful errands ; and, although there was in various parts of the world what some of their friends called " any old oil " being used in Diesels, yet generally speaking the Diesel seemed unfortunately very selective in its tastes, and rejected just those very oils which were to be depended upon in any large quantity as fuel oils.

Every engineer felt that the burning of residual oil under boilers was absolutely wasteful and one of those things which ought to be done away with if it was at all possible. It seemed to him, however, to be very doubtful whether much progress was being made in adapting the Diesel engine and the semi-Diesel engine to the use of those heavier fuels, and the paper gave a great deal of confirmation to that view ; and the development of that particular type of engine was likely from that cause rather to localise itself, i.e. the particular types were likely to be developed that would use the oils that were available in particular countries or districts.

That might be suitable for land services, but, looking at the question from the sea-going point of view, what they would like to see would be an engine that would first of all develop a much higher power per cylinder than was obtained at present, and secondly would not be so fastidious in its tastes, but able to use, from port to port all over the world, the oil that might happen to be there available, within reasonable limitations of quality. Those who had for sale in different parts of the world very high-grade oils that suited the Diesel engine, and who were able to get a good price for them, might look at the matter with rather different eyes, but looking at it broadly, from the point of view of the development of the general sea-going trade of the country, and the desirability of having a most economical fuel-user in ships, one could only hope that the development would take place along lines of that nature, that would enable a much wider range of fuel to be used than appeared to be practicable at the present moment.

The author had held forth mainly the hope that a supply of oil that would suit the Diesel engine would be forthcoming from the

development of shale and lignite. He thought that development lay a little ahead. As the members knew, the gas-oil that was distilled from shale in this country, and in other countries where shale was worked, was very limited in quantity and commanded a very high price as gas-oil. Therefore they could not look to that source, at any rate at present, for any very great supply of oil for those particular types of engines.

Mr. J. C. Templeton said he had been very keenly interested in the author's statements in regard to heavy-oil engines, but he did not altogether gather whether the author was against petroleum-residues or against tar-oils. The author seemed to condemn both more or less equally. In his opinion the question rather narrowed itself down to one of supplies. So far as quantities were concerned, the figures the author had given for lignite oil were in the neighbourhood of 60,000 tons, whereas the quantities of heavy petroleum oils produced were near 35,000,000 tons. It seemed to him, therefore, that what had to be provided for was mechanical adjustment to suit the various quantities of petroleum oils far more than legislation to suit the small quantities of tar-oils.

He thought many of the Diesel-engine makers themselves were to blame for the state of chaos in which the user found himself at present. There were many experts who gave specifications for oil, one of whom would advocate 5 per cent. of asphalt as the maximum which could be used, while another might put the maximum figure 15 per cent. and the makers themselves, in the course of conversation, might even indicate as high as 25 per cent. The margin between 5 and 25 per cent. was a very wide one, and if anything went wrong in the running, the user was told that he should have used oil of a different specification. That sort of thing had resulted in the very conservative use of the Diesel engine. When it was remembered that everyone was crying out for the conservation of fuel, and it was found that, out of perhaps 35,000,000 tons of petroleum fuel oil produced annually, only 1½ or 2 per cent. was used in internal-combustion engines, it seemed to him that here was one great avenue whereby the conservation of fuel could be realised. He thought it was more up to the Diesel-engine makers themselves than to the uninitiated public to popularise the Diesel, and to design their engines so that they were able to utilise, by small adjustments, all the classes of liquid fuels produced, whether light petroleums, heavy oils or tar-oils.

Mr. N. A. Anfilogoff said he desired to quarrel with the engine manufacturers for the very loose way in which they used the term "crude oil." They frequently said that a certain engine was a

Diesel engine, and therefore could use crude oil. As the President had stated, however, it was very often found that a Diesel engine would not work on what was termed "crude oil," but which was really residual oil on which it was intended that the engine should run.

If it came to a question of supplying gas-oil for the use of Diesel engines, no question then arose of the conservation of oil. A great deal of oil was wasted if it had to be distilled. There was loss by evaporation; there was loss owing to the fact that the residual oil after the gas-oil had been taken off was useless from a commercial point of view, except as furnace fuel, unless the crude oil was able to produce lubricating oils. This was more especially the case with some of the oils which contained a large percentage of asphalt, as this commodity happened to be a drug on the market, it would be a great deal better for the petroleum trade and for the engine-makers if the so-called Diesel engine, which was advertised as being able to use crude oil, was actually able to work efficiently on residual oils. When it came to the use of gas or solar oils and hot bulbs he could well conceive situations in which a hot bulb would prove particularly obnoxious. On some of the oilfields, for instance, or in places where a great deal of vapour or gas from the wells existed, there was a great risk of fire from the hot bulbs. It was unforgivable that kerosene should be used as fuel for engines. If the lighter distillates have to be used in this way, hot bulbs should be replaced by electric ignition.

Dr. W. R. Ormandy said it was pretty obvious to him that the audience, in so far as they had spoken, knew a great deal more about oil than they did about the Diesel engine. The general sort of complaint that the average or even the specialised engineer could not make a highly-efficient engine, which was capable of running on any liquid which was poured into it, was entirely justified. Diesel started out in the first place to make an engine which would work with powdered coal. He was not able to do so, and in view of the paper which had just been read, in which the author stated that the presence of ·06 of ash was the maximum amount that was allowable in a liquid fuel having 50 per cent. more heat-value than any coal which might be employed, and thinking of the sort of coal which the Government allowed them to get at the present moment, it did not require a very eminent engineer to realise what would happen to an engine which was fed continuously with some of the finely-powdered material which was delivered to the bulk of their houses, and called "round coal," or at any rate charged as such.

The author, in his position as engineer to a Company which

insured and made themselves responsible for the running of Diesel engines, had almost unequalled facilities for finding out what did happen to Diesel engines and semi-Diesel engines when they were fed with fuel of that or the other character. The author had endeavoured (and had very well succeeded) in pointing out that the Diesel and semi-Diesel engines, as at present constituted, were capable only of using fuels which came within certain well-defined categories. He had pointed out the reason why certain oils could not be used, how attempts had been made to get over the difficulties, and how, for instance, his Association, which was connected with the Diesel Engine Users' Association, had already agreed to a specification which was wider in its scope than that which was allowed by the German Diesel Engine Users' Association, from which he supposed it might be inferred that the English Diesel engine as now constructed was slightly less sensitive, and was capable of taking a slightly wider range of fuel than the German Diesel engine at the time when that specification was published.

There were so many points in the paper which opened out subjects for discussion that he hardly knew where to begin. He did not think the present was the time or the place to deal at any length with the engineering side of the subject; that was rather a matter for discussion at the Institution of Mechanical Engineers, or the Institution of Automobile Engineers. Therefore he would say nothing about the engine and the valve system, but he would like to ask Mr. Anfilogoff where he came across oil fumes on an oilfield which were capable of igniting by coming in contact with the hot bulb of the Diesel engines. Petrol required an ignition-temperature of something approaching a white heat, and it could not be ignited with the glowing end of a cigarette unless a bit of paper happened to catch it on fire, so that he could not see any possible source of danger from the hot bulb of a semi-Diesel engine coming in contact with any vapours that were likely to be found on an oilfield.

When it was borne in mind that the amount of time during which the fuel had to be burned in a Diesel-engine cylinder varied from $1\frac{1}{2}$ down to $\frac{1}{2}$ of $\frac{1}{100}$ part of a second, which was equivalent to the ratio of 3 to 5 hours in relation to one single minute, and that during that period the oil had to be put in, and the present means of indicating the engine were sufficient to show whether a small quantity injected in that short space of time was homogeneously distributed into the cylinder, one realised the difficulties the engineer had had to face. He thought progress would come, but it would come slowly in the direction of using asphaltic oils, for the very simple reason that asphalt was not volatile. If any of the asphaltic

oils got on to the hot surface of the hot bulb, they deposited carbon, and a short space of time sufficed to render the hot bulb incapable of use. On the other hand, if air-injection systems were applied in the Diesel engine, it was almost inevitably certain that the oil during injection would get on to the cylinder-head before it had thoroughly atomised. The difficulty could be realised, for instance, of the first drop of oil into the cylinder being fully atomised by the air which followed it. In the case of solid-injection systems, the difficulty was very much greater. Then there was the difficulty of preventing any drip which might collect on the nozzle, and those difficulties were not going to be overcome easily.

He took exception to the author's estimation of the temperatures, for instance, the statement made that at light load the bulb showed colour in the dark at a temperature of 750° F. He thought the author would have to add 230° or 240° to that figure to make it right. The lowest visible temperature in a dark room to what was known as a dark-accommodated eye was 525° C., which was 977° F., so that all the author's figures required pushing up somewhat.

He desired in the next place to mention an aspect of the matter which the author had referred to very briefly, namely, the ignition-temperature of oil and its relation to the suitability of the fuel for Diesel or semi-Diesel engines. Reference had been made to Harold Moore's system of determining what was known as the ignition-temperature in oxygen. The method employed was quite simple. There was a block of steel containing in the middle a little platinum crucible. The block of steel was heated to a temperature of, say, 260°, 270° or 280°, as the case might be, and a current of oxygen, sent through a coil cast in the steel, went into the crucible, and a drop of oil was allowed to fall in through a hole in the lid. If the block was hot enough, an instantaneous explosion followed the entrance of a drop of oil. If it followed instantaneously, it was known that the block was too hot, and another try was made at a slightly lower temperature, until a temperature was found at which it required perhaps 10 or 12 seconds before the oil gave a feeble explosion. If it was cooled lower than that, there was no explosion at all. It was rather an extraordinary thing that the temperature of ignition so found varied enormously. For instance, benzol was 565° C., toluol 520° C., xylol 480° C., crude creosote oil about 415°C., naphthalene 405° C., tar oil 307° C., petrol 270° C., and so on. The most noticeable feature of those variations was that benzol, with the simplest formula of the lot, took a very high temperature before it would light. Generally, the more complex the formula of the body, the lower the temperature at which ignition took place.

What the Diesel engine man wanted was an oil which would self-ignite at the lowest possible temperature within reason (he did not want to use ether) because then he could get the thermal efficiency due to the Diesel cycle at a low pressure, and consequently did not require such a powerful and heavily-built engine. When during the war they had to turn over to tar-oils, they were faced with the difficulty that the creosote oils required a temperature of somewhere about 150° to 200° higher to self-ignite than the paraffin oils, and Mr. Prentice, the Chairman of the Diesel Engine Users' Association, proposed that the chemists should spend their energies in endeavouring to make creosote oil self-ignite at a lower temperature. He told Mr. Prentice on that occasion—and he wished to repeat it—that chemists could not alter natural facts. It was a fact that creosote oils ignited at that temperature, and all they could do was to endeavour to convert creosote oil into something else. That was being done for them by the gas works. The introduction of the vertical retort had succeeded to a certain extent in converting the tar which was produced into paraffin oil instead of creosote oil, with the immediate consequence that vertical-retort tar-oils would work at a very much lower pressure without as many precautions as were requisite in the case of horizontal-retort oils.

The author pointed out also one of the difficulties of utilising tar-oils, namely, the fact that they might, and often did, contain very finely-divided carbon. The tar from a vertical retort contained very much less carbon than that from a horizontal retort, and certain experiments which were carried out in Germany a few years ago, just before the war, gave the reason for it. If the tar was taken as it came over from a horizontal retort, and the main leading the tar away was put through a jacket, so that it was kept hot, the vapours not being allowed to condense at all, but being run into a cooler, where they were allowed to cool down in temperature perhaps 100°, or as much as was necessary to bring them below the dew-point of the tar which was in them, but not allowing the creosote oils to separate out, a thin fluid tar was obtained from a horizontal retort, which had been known to contain less than half of 1 per cent. of carbon. The reason carbon was obtained in tars as they were distilled at present was because all gas engineers adopted the stupid system of distilling the coal, condensing the whole mess of tar, oil, benzol, ammonia and water together into one filthy sludge, which they sold to a tar distiller, who proceeded to heat it up, converting 20 per cent. of the material into carbon, which was in suspension, and distilling off a few valuable portions.

If, instead of doing that, they condensed the vapours fractionally,

and let the tar come out first then the creosote oil, and then the naphtha, they would get a much higher yield and much purer products. They might say it could not be done, but the fact was that they were doing so well as they were working at present that they were "quite satisfied, thank you." It had been done, and they knew that it was being done. He had personally seen a range of coke-ovens passing the whole of the gas into a series of seven scrubbers in a row, each scrubber being kept cool by pumping in the condensed liquid from the succeeding scrubber, so that they could just bring the temperature down in each scrubber to the dew point of whatever product was required, and they were producing soft tar, heavy creosote oil, light creosote oil, paraffin oil fractions solvent naphtha and light naphtha; then the gases were cooled down in order to take out the bulk of the water, and the gases were passed to an ammonia scrubber and tower, where the ammonia was taken out. It could be done, and it was being done on the Continent, and, if it was really desirable and necessary that oils suitable for Diesel engines should be obtained, they could be obtained in that way.

The only other point which he would mention was the possible utilisation of lignites, in connection with which the author had quoted a figure of the amount of lignite-oils produced in Germany. That figure was only for one small Province in Germany. As a matter of fact, in Germany and Austria something like 50,000,000 tons of lignite were distilled. The production of lignite-oil in Germany was the salvation of Germany during the war, in that, had it not been for the production of that oil, during certain periods of the war the German submarines and engines using Diesel oil would not have been able to continue work.

With regard to the Bovey Tracey deposits, he was glad to say that active steps were being taken to put down further bore-holes to find out the exact nature of those lignites, with a view to their subsequent distillation and, in so far as they were not suitable for distillation, for their briquetting—at any rate for making them into a useful asset.

Mr. J. L. Chaloner said he desired to disagree with the statement made in the first paragraph of the paper that there was really nothing new to be said about the internal-combustion engine, because he thought the country was on the eve of a revolution in that matter. An engine was being developed in this country at the present moment which was purely of a British type, and which in his opinion had great advantages over both the so-called semi-Diesel and Diesel engine.

The author had referred to the question of a distinction between the semi-Diesel and Diesel engine, and had given as a definition of the semi-Diesel, that "the heat derived from an uncooled portion of the combustion-chamber, together with the heat generated by the compression of air to a moderate temperature, ignites the charge." The author has also shown a section of the Crossley engine, from which the members would have noted that there was no uncooled portion of the chamber which was in contact with the fuel, and therefore the definition of semi-Diesel would not apply in that case. Either the definition would have to be altered, or a third definition must be formed which would refer to the particular type in question. It was an engine which was to his mind a solid-injection Diesel engine, and disposed of the disadvantages of the hot bulb of the semi-Diesel engine, and the air-compressor of the Diesel engine. In his opinion it was an ideal engine which would in the future be largely developed in connection with industrial and marine purposes.

The question of air-blast and solid injection had been raised in the paper. If one analysed for a moment the process which had to be adopted during the period of combustion to get the right sequence of operations, it would be found that the degree of combustion very largely depended on the following five principal conditions:—atomisation, vaporisation, the mixture of fuel and air, dissociation and combustion. It was necessary to work along these lines in order to get satisfactory combustion, thereby keeping down the exhaust temperatures, and giving the desired thermal efficiency. As had been seen in the slides, in the fuel-valve casing the air forced the fuel through a series of holes and the degree of atomisation depended entirely on the maximum degree of mixing between the air and the oil. The oil could therefore be imagined as entering into the highly-compressed air in the combustion-chamber in the form of innumerable globules surrounded by air. The smaller the globules the larger the volume of air surrounding each of them, and therefore a certain time would elapse for the compression-heat to pass through the layer of air to the globules before combustion would commence.

In the case of the solid-injection engine that was not so. Oil was being atomised mechanically, and therefore as soon as it entered the cylinder it came in direct contact with the heat of the compressed air. The total number of designs built on these lines both in this and other countries was about twelve, and although it represents a very small fraction of the total number of oil-engine designs constructed in the world, it indicates the tendency of

modern oil-engine construction. Some of these engines were in a position to burn residual oils of more or less highly asphaltic contents, and this proved in his opinion that the sequence of operations was more concisely followed in the solid-injection method than where atomisation was effected by air blast. The latest types, Campbell, Crossley, Ruston and Vickers are examples of this new principle. The author made the statement in his paper that "it seems fairly obvious that perfect combustion will not be so readily obtained with the heavier and more viscous fuel oils as would be the case with the blast system of injection." This statement was quite correct, but as he had already pointed out, the solid injection system could deal equally well with heavy and viscous fuel oils, and consequently this type of engine could be considered as less sensitive, and good for a wider range of different grades of fuel.

The author also referred to "the indisputable fact that in this system the entry of the compressed air lowers the temperature in the immediate vicinity of admission, owing to its expansion, and this at the precise moment when it is least desirable." He did not know whether the author had analysed any heat-balance sheets, but from certain experimental data, it was determined that the heat absorbed in injecting the oil represented approximately ·5 per cent. of the total heat-value of the oil, and if that percentage was taken up in lowering the temperature, the Diesel engine must be a very sensitive engine to take notice of it. Another interesting point was the exhaust temperature, which for the same rated H.P. per cylinder was very much higher with tar-oil than with residual-oils, as the following figures show—

B.H.P. per cylinder.	Grade of oil.	Exhaust temperature.
40	Residual	893° F.
40	Tar-oil with ignition oil	1089° F.
42	Tar-oil	1076° F.

Four-stroke cycle and vertical type in each case.

Comparing those figures with data collected from the latest type of solid-injection heavy-oil engines, it would be found that the exhaust-temperature of that particular type of engine was lower to the extent of approximately 75°, which indicated that the combustion was more complete, and the thermal efficiency was equally high.

In the Crossley engine it was a remarkable fact that between full load and half-load, there was practically no difference in the fuel-consumption; while in a normal Diesel engine the consumption varied with the load, and was probably 5 to 10 per cent. higher at

half-load than at full load. With regard to the question of spontaneous ignition-temperature mentioned by Dr. Ormandy, his own personal experience showed that the present method of determining the values of spontaneous ignition-temperature were more or less useless to introduce into fuel-oil specifications. The experiments of Constam were mentioned in the paper. It would be found that in that research something like 100 different oils had been analysed, and it was a remarkable thing to him that in the case of coal-tar oils the spontaneous ignition-temperature with oxygen in a platinum crucible was practically the same, although their origin was from all kinds of plant—vertical, intermediate, and horizontal retorts and coke-ovens.

In connection with the question of ash-contents, the author had stated as an example that 2 cwt. of ashes would be accumulated in the combustion-chamber of the exhaust. He thought the author must have a rather excellent filtration system in his exhaust-line, if that was the case.

The author had also asked him to say something about raw tars and tar-oils. A leading German authority had summed up the situation in the following way: that coal-tar and coal-tar oils were not available in sufficiently large quantities for industrial and chiefly marine purposes, were not sufficiently consistent in quantity, and caused too many break-downs during running, which were up to now attributed to the engine, whereas they were distinctly due to the fuel. When a statement like that was made in Germany it was rather serious, because it must be admitted that Germany had had more experience of tar and tar-oils than this country; there were better facilities, because the retort gas plant in Germany had been developed very much more than in England, and therefore they had had a better quality of tar-oil available for the purpose. If the conclusion was that the tar-oils were causing trouble which was originally attributed to the oil-engine, the question arose whether tar and tar-oils would really give that benefit which was expected from them.

Any quantity of residual oils were available, and the President had most rightly pointed out that those available oils must be made use of, and it was not for engineers to say they wanted any particular oil specification. If they could not get the oil, they must design an engine suitable to run with the available oil, and he desired to say again that the engine at present built in this country on the new lines he had described was the engine of the future; he was proud to say it was entirely a British idea, and that the Germans had not got a single engine to equal it.

Mr. Gordon Pitt said that, as a very recently elected member of the Institution, he found himself with just sufficient pluck to say a few words, because two of the principal contributors to the discussion had been Mr. Anfilogoff and Dr. Ormandy, at the feet of both of whom he had had the good fortune to sit at different times for various parts of his training, and, while he would hesitate very greatly before he attempted to compare their respective merits, he thought he had perhaps special opportunities for comparing their respective points of view. It seemed to him that the essential point brought out during the discussion was the integral difference in the point of view with which the Diesel engine problem had been attacked by the chemist and by the engineer. There had been a certain tendency on the part of the chemist to say that the reason the Diesel engine had not done better than it had was the fault of the engineer, i.e. that the design was not good or at least not the best for the oils available; and there had been a certain tendency on the part of the engineer to blame the chemist by saying that the best fuel was not obtainable. They were surely not particularly concerned to-day with Dr. Diesel's original idea: Dr. Ormandy had pointed out how far away they had got from it now. What they were really concerned with was the provision of an engine which would give satisfactory service with the most available and, from that point of view, the cheapest fuel. The engineer had obviously gone in the direction of improvement of the design of which he found himself put in possession to begin with, and he found that one of the most obvious lines of improvement was to get a better fuel. Every man who ran an engine soon desired, among other things, to improve his class of fuel, and he was rather inclined to think that the engineer and designer had gone rather too readily perhaps to the chemist and said: "If you will give me a better fuel I can get a better result; I can get more brake horse-power per lb. of fuel, higher efficiency," and so on. The tendency at the present time, as pointed out by Admiral Dumas in his recent paper, was to use oil to an increasing extent, but without always watching whether it was being used in the most efficient way; and it seemed that their programme at the present moment was not to improve the Diesel engine according to some more or less hard-and-fast definition of what was a Diesel engine, i.e. not to be too empirical, and say the Diesel engine must correspond with such and such standard regulations, and therefore gas-oil was required for it, or a distillate, or oil that had got less than a certain quantity of asphalt in it, but to look round and see what were the available supplies and types of oil, and set about producing an engine which would give,

to begin with, reasonably satisfactory results from such oils, and then set about improving that design until it gave better results from the classes of oil that were available for the purposes with which they were now dealing.

Mr. E. H. C. Craig thought it must be recognised that shale-oil must not be judged by the shale-oils that were being obtained in this country at the present moment. He thought it would be found, perhaps when those wonderful (!) Norfolk shales were distilled, and giving thousands of tons of oil a day—(he hoped it would happen)—or when the Dorset shales were used for distillation, that probably a very much larger percentage of good gas oil would be obtained than from the older Scottish shales. There had been some discussion between Mr. Anfilogoff and Dr. Ormandy upon the point whether the hot bulb of a semi-Diesel engine was likely to fire vapours on an oilfield. He quite agreed with Dr. Ormandy in thinking that it never would fire vapours, but he was not sure that, when there was a spray of light oil in the air, when a well had just come into operation and the whole area was full of spray of oil and gases, a very hot body would not be able to ignite it, because fires had started in cases in which one could not believe it was possible for the vapours and spray to have got to any open fire, and yet there had been a flash back to the derrick, and the derrick had been burned.

With reference to the question of the development of oils in this country, to which Dr. Ormandy had referred, they might be perfectly certain that oils of various kinds would be made, and made very soon. In that connection he was glad to say that some of the seed sown by the Petroleum Research Department was beginning to show a tender leaf above ground. In that respect they were something like the sower in the parable. They sowed the good seed, and some of it fell by the wayside—say in Northumberland Avenue—and the officials sprang up and choked it; some of it fell upon stony ground—say among the scientific public—and they gobbled it up, but no result came from it; some fell on shallow soil—say in Norfolk—and it sprang up amazingly, but 'the heat of the day' has not come yet: but some portion fell on good ground, and he hoped it would bear fruit in places like Bovey Tracey and other parts of Devonshire. In that connection he desired to mention that they had supplied a good deal of the information to the Geological Survey, which had been published in their Memoir. They hoped that the seed sown in Devonshire in connection with its lignites would return—he did not know how many fold Dr. Ormandy would be satisfied with, but at any rate a good production.

Mr. Anfilogoff said that, like most of the members present, he held Dr. Ormandy's views in great respect, but he earnestly advised the members of the Institution not to attempt the experiment of igniting a can of petrol, for instance, with a lighted cigarette, in case the petrol had not heard of Dr. Ormandy's views. He had found, he regretted to say, that a slipping friction-clutch caused a fire of petrol vapour in close proximity. He did not know whether the members had noticed the fact, but, with a hot bulb of 1400° or 1500° F., the least speck of dust falling on the bulb immediately created a spark, which would probably ignite petrol or its vapour. Anyway, he would not like a hot-bulb semi-Diesel engine working on premises in which petrol was stored.

Mr. A. J. Wilson, in his reply, said that the President had referred to the hopeful prospect of employing Diesel engines for marine purposes, more particularly for the mercantile marine. While agreeing with him that the great weight of such engines as at present designed precluded their use in high-speed vessels such as light cruisers and the like, very considerable progress had been made of recent years in equipping cargo tonnage. The position to-day is that 44 vessels, equipped with the Burmeister and Wain type of engine, are in service, representing a total of 355,000 tons D.W., while the well-known Dutch builders, Messrs. Werksporn of Amsterdam have engined 25 vessels with a total D.W. capacity of 64,000 tons. There are also on order upwards of 150 vessels engined by various firms, none of the ships being of less than 2,000 tons D.W., while 10 at least are of 13,000 tons D.W. capacity.

As indicating the comparative weights of steam machinery and Diesel engines, the lightest type of Diesel engine he was acquainted with was the Vickers type of submarine engine, an illustration of which appears in fig. 17. This design of Diesel engine gave one brake horse-power for 58 lbs. weight of machines, whereas a geared turbine installation would give one shaft horse-power per 30 lbs. weight, or less in the case of some torpedo-boat destroyer installations.

The next lightest marine Diesel engine at present being manufactured was the Werkspoor engine, which is of the 4-stroke, single acting type and is made in two standard sizes, of 1100 B.H.P. with six cylinders, and 1680 B.H.P. also in six cylinders. In the case of the smaller size, the weight came out at 387 lbs. per B.H.P., and comparison is interesting of the weight of this 1100 B.H.P. Diesel engine complete with all accessories down to the thrust-block

with that of a steam-engine of equal power. The former weighed 190 tons as against the latter's 186 (including boilers).

A still heavier type of marine Diesel engine (shown on the screen) was the Burmeister & Wain engine, now being installed in large numbers by the Danish firm, and also by Messrs. Harland & Wolff.

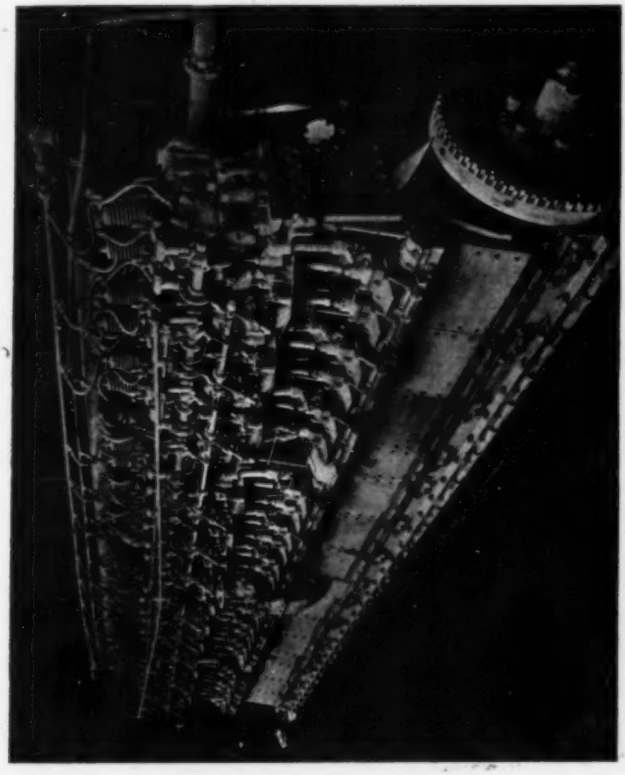


FIG. 17.

The engine illustrated weighed approximately 520 lbs. per B.H.P., and gave a total B.H.P. of 3200 in six cylinders. A previous lecturer had referred to the limitations of size which the Diesel-engine manufacturers could offer, and as indicating a step in the right direction, an illustration was given of a 4000 B.H.P. six-

cylinder Diesel engine as made by Messrs. Sulzer Brothers. This engine was of the 2-cycle type, and was eclipsed in power per cylinder by a 2000 B.H.P. single-cylinder engine which Messrs. Sulzer had built for experimental purposes. He could not point to any vessel actually fitted with an engine of anything like that

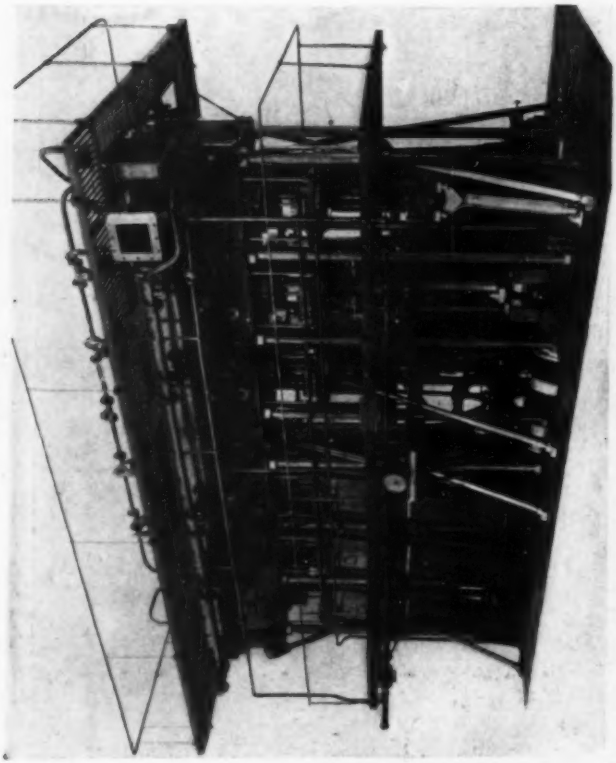


FIG. 18.

power per cylinder, but he had no doubt that the engine-builders would be quite ready to undertake the work if desired.

The President had rightly pointed out that if any conservation of oil was to be effected, the engine-manufacturers must produce an engine capable of using oils which could be obtained almost anywhere, and certainly the demands of the oil-engined mercantile

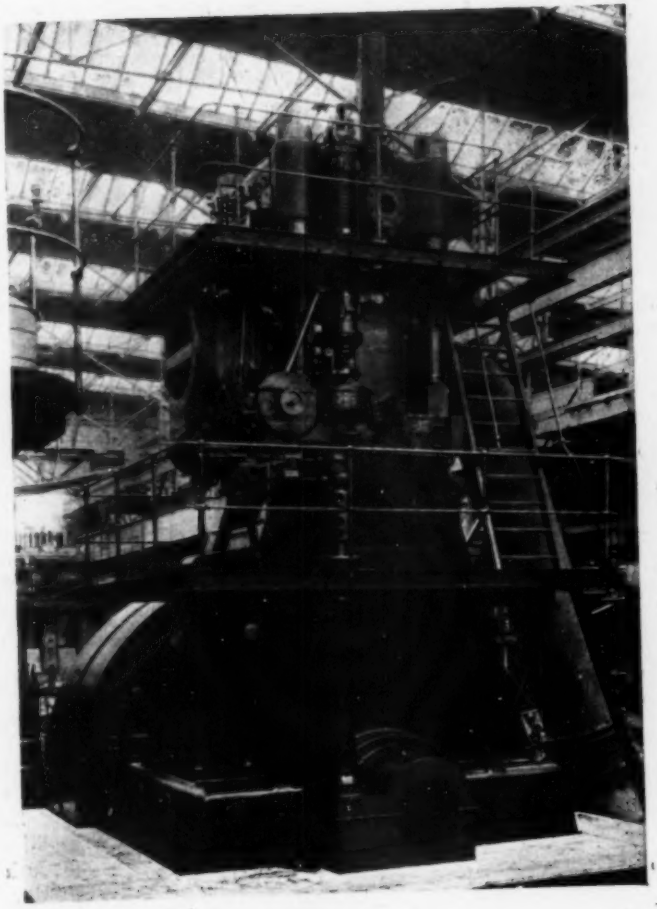


FIG. 19.

tonnage would provide an incentive to do so. The author looked to the 2-cycle engine as being the most likely to provide answer to that demand, although the 2-cycle marine-type Diesel oil-engine had not done so well as the 4-cycle engine, up to the present. He did not, however, regard the future of the 2-cycle engine as by any means a limited one, on account of the limited experience so far gained with it. This type of engine, besides having a greater power per cylinder than its 4-cycle rival, can be designed entirely to eliminate exhaust-valves, and without exhaust-valves to consider one could use oils having a comparatively high ash-content. This would at once open a much wider range of selection for fuel.

Mr. Templeton referred to the somewhat extravagant claims made by oil-engine manufacturers as to the percentage of asphalt which their engines could use. One or two of the large firms had seen the wisdom of providing an expert chemist and a laboratory as an essential part of their organisation, in order that they might acquire the necessary knowledge as to the suitability, or otherwise, of fuel-oils used by their engines when on test, and the worst offenders in the matter of statements as to permissible asphalt-content were generally small firms, who, whatever they might know about oil engines, certainly knew very little about oil.

Dr. Ormandy referred to the early ideals which Dr. Diesel sought to attain for his engine, in regard to its ability to burn anything in the shape of either liquid or powdered fuel. The hopes and disappointments which the inventor experienced are very fully dealt with in a paper read by Dr. Diesel at Charlottenburg on the 22nd November, 1912, before the Schiffbautechnische Gesellschaft. From this it would seem that Diesel designed his engine for the use of petroleum oil, and that the first experiments were actually made on that fuel, although subsequently all sorts of fuels were used, including coal gas and powdered coal.

The author wished to thank Dr. Ormandy for correcting the figures given in the paper as to temperatures of hot bulbs. The temperatures put forward by the author were based on what he had considered good authority, but in view of the better facilities which Dr. Ormandy had for obtaining accurate data in such matters, he did not propose to dispute that gentleman's correction.

Dr. Ormandy also drew attention to what might otherwise have passed unnoticed, and that was the result of the research work conducted by the Diesel Engine Users Association, the outcome of which had led to the British users of Diesel engines being able to employ creosote oils every bit as successfully as the Germans and,

in fact, to obtain satisfactory performance on a less stringent specification for the fuel.

Dr. Ormandy's remarks on the methods employed by the British Tar Distillers and Tar Producers were particularly valuable, and it was to be hoped that the present crude methods of both making and refining tar would be superseded by a more enlightened procedure. At any rate, the tar-producing fraternity had still got plenty to learn, however much they might be satisfied with things as they are on purely commercial grounds.

Mr. Chaloner had ably dealt with the difficulty of classifying Semi-Diesel engines, and in the author's opinion hard and fast definitions were not possible when so many of the types now in use were on the border-line at the Diesel engine end of the scale, and he did not propose to re-open the controversy as to what is a Semi-Diesel engine.

As regards Mr. Chaloner's doubts regarding the lowering of the temperature in the combustion-chamber due to entry and expansion of compressed air, the data given by him were certainly very interesting, but although it might be shown from the heat balance that only $\frac{1}{2}$ per cent. was absorbed in injecting the fuel, the author was still of the opinion that the loss occurring as it did at a very critical period in the cycle was a disadvantage. At any rate he was sinning in good company, if at all, in saying so.

What Mr. Chaloner had said about the present-day German opinion on the use of tar-oil was a peculiarly valuable comment in view of the fact that in Germany very much better grades of tar-oil had been used, and a longer experience obtained with the use of such oil had been obtained. It only confirmed the author's own opinion, i.e. that unless a high grade of creosote oil was available, it was preferable to use a petroleum residual, even if of low grade.

He wished to thank other speakers for their remarks, and the members generally for the very kind manner in which they had received the paper. There was an obvious enthusiasm for the subject shown by both the oil producer and the engineer, and with the country standing as it did on the threshold of a decade which is destined to be famous in the development of oil-engineering and oil-production, that enthusiasm would take them a very long way.

The meeting then terminated.

Mr. Percy Still subsequently wrote as follows :—

In dealing with various methods of using tar-oil in Diesel engines without abnormally increasing the compression, Mr. Wilson refers to experiments carried out by Rieppel in mixing tar-oil and gas-oil in various proportions, which showed that, for good running on

variable loads, 25 per cent. of tar-oil was the maximum permissible. It would be interesting to have further information as to the manner in which these mixtures were carried out, as to whether they make a permanent satisfactory mixture, or whether, in view of the difference in specific gravities, there is any tendency for the two classes of oil to separate out, if stored for some time.

During the war many Diesel engine users who commenced using tar-oil were considerably troubled by the deposition in cold weather of napthalene crystals in the tank-wagons and in their storage-tanks, if means had not been provided to maintain these at a suitable temperature. It was stated that the addition of 25 per cent. of petroleum fuel-oil to the tar-oil prevented the deposition of napthalene crystals. Generally speaking, however, mixtures of tar-oil and petroleum fuel-oil did not give very satisfactory results, though a considerable quantity of such fuel was supplied during the war. In the discussion on Mr. Geofirey Porter's paper on "Tar Oil Fuel and Diesel Engines," at the meeting of the Diesel Engine Users' Association on 21st June, 1917, reference was made to the tendency in such mixtures to the formation of a gelatinous substance which might block the oil pipes and pumps, and it would appear to be desirable to obtain further definite information on the methods of production of suitable mixtures of liquid fuel for use in internal-combustion engines.

It is evident, indeed, that the whole subject of the production and preparation of suitable liquid fuels for oil-engines and for furnace-work requires much further investigation. Cases are known, for instance, of a certain tar-oil working satisfactorily in a Diesel engine, and yet when samples of the same tar-oil have been sent to be used elsewhere in Diesel engines built by another firm, but working under similar conditions, the fuel has been found to be unsatisfactory for use. The Diesel Engine Users' Association have lately suggested, and have taken first steps to form, a Research Association for Liquid Fuels. A Provisional Committee has been formed under the scheme of the Department of Scientific and Industrial Research, and the object is more particularly to encourage the application to internal-combustion engines of suitable liquid fuels extracted from the natural resources of this country.

The discussion on Mr. Wilson's paper has brought out rather clearly the tendency on the one hand of oil-engine manufacturers to take the view that fuel-oil producers should produce oils to suit their particular engines, and on the other hand the tendency of fuel-oil producers to consider that the engine manufacturers should be able to adapt their engines to work satisfactorily with the class

of fuel oil that they can most conveniently supply. The proposed Research Association would provide a solution of this difficulty, inasmuch as Diesel and semi-Diesel engine manufacturers, tar-producers and tar-distillers and others interested in the object in view, besides the fuel-oil users themselves, are taking part in this movement. It is hoped this may have good results, in the establishment in due time of an important national industry on a considerable scale.

Forty-Third General Meeting.

This Meeting was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday, 20th January, 1920, Sir Frederick W. Black, K.C.B. (President), occupying the Chair.

The Members of Council present were Capt. R. W. Barnett, M.P., Messrs. H. Barringer, E. H. Cunningham Craig, Arthur W. Eastlake, Dr. W. R. Ormandy, Messrs. T. C. Palmer and Robert Redwood.

Letters of regret for unavoidable absence were received from Sir John Cadman, Dr. A. E. Dunstan and Dr. F. Mollwo Perkin.

The Hon. Secretary (Mr. Arthur W. Eastlake) announced that the following gentlemen had been elected :—

As *Members :*—James Bryson, Geoffrey Haly and Richard Kenneth Richardson.

As *Associate Members :*—William Edward Douglas Cole, Arthur Lloyd Eastlake (transference from Student), Herbert George Edward Greville, Edward Jasper Horley, Edwin Cooper Scott, and William Rupert Alfred Weatherhead (transference from Student).

As a *Student :*—William Graham.

As *Associates :*—William Henry Edwards, Charles Cuthbert Michelsen and Montagu Summers.

The President, in introducing the lecturer, said Mr. Moore had had a very wide experience as a research chemist and engineer. He had been with the well-known firm of Merrilees, Bickerton & Day, and was now a consultant in practice at Manchester. The subject of the paper was one not only of great importance but of very considerable profundity and difficulty ; but he (the President) hoped that that would not deter anyone from joining in the discussion.

The following paper was then read appropriately illustrated by lantern slides :—

Spontaneous Ignition-Temperatures of Liquid Fuels.

By HAROLD MOORE, M.Sc.Tech., A.I.C., F.C.S., *Associate Member.*

IN the course of researches on liquid fuels for internal-combustion engines it became evident that the influence of the temperatures of spontaneous ignition of the various fuels upon their behaviour in internal-combustion engines was of primary importance. The difficulties experienced in obtaining regular ignition when attempting to burn oils originating from coal-tars in Diesel engines, and the high degree of compression possible in engines operating on the constant-volume cycle when running on alcohol or benzol, suggested that some property of the fuels other than the properties usually determined by analytical examination influenced their behaviour in the engine. As a result these investigations upon the temperature of spontaneous ignition were undertaken.

The following definition of the term "temperature of spontaneous ignition" was adopted. "The temperature of spontaneous ignition is the temperature at which a substance surrounded by oxygen or air at the same temperature will burst into flame without the application of any spark or other local high temperature."

In the following notes the temperature of spontaneous ignition will, for convenience, be referred to as the "ignition-point." This property has no connection with the flash-point or the burning-point. The actual bearing of the investigations upon the behaviour of fuels in internal-combustion engines and upon engine design will be treated later.

During the last decades numerous investigations have been made on the subject of spontaneous ignition. In these, explosive gaseous mixtures have received the most attention. The following methods have been used* for determining ignition-points of gaseous mixtures:

(1) A bulb containing the explosive mixture was plunged into a bath maintained at a constant temperature.

(2) The explosive mixture was passed through a tube immersed in a bath, the temperature of the bath being gradually raised.

(3) The explosive mixture was subjected to adiabatic compression, and the temperature of the mixture at the ignition-point calculated.

Dixon and Coward employed for their determinations of ignition-points two concentric tubes heated by an electric furnace, one component of the mixture passing through the smaller tube, and the other through the annular space surrounding it. The gases were

* Dixon and Coward: *Journ. Chem. Soc.*, xcv, 514. 1909.

allowed to mix at the end of the inner tube, which was the shorter. The temperature was measured by means of a thermo-couple situated at the outlet of the inner tube.

McDavid* determined ignition-points by blowing soap bubbles containing gaseous mixture, and then bringing these bubbles into contact with a heated coil or a heated iron block, the temperature of the coil or block being measured by means of a thermo-couple pyrometer. This method has been criticised by A. G. White and T. W. Price.†

The results obtained by various experimenters do not agree very closely. A table of results has been compiled by McDavid,‡ from which the following values for hydrogen-oxygen mixtures have been extracted.

Observer and Reference.	Ignition-points.
Krause, A., and V. Meyer, *Ann. Chem.*, cclxiv, 85. 1891 Askenasy, P., and V. Meyer, *Ibid.*, cclxix, 49. 1892. Freyer, F., and V. Meyer, *Zeitschr. physik. Chem.*, xi, 28. 1893.	518°—606°
——, ——. *Ber. deutsch. chem. Ges.*, xxv, 622. 1892.	700*
Gautier, E. J. A., and H. Hélier, *Compt. Rend.*, cxxii, 556. 1896.	840°
Hélier, H., *Ann. Chim. Phys.*, 7, x, 521. 1897.	845°
Bodenstein, M., *Zeitschr. physik. Chem.*, xxix, 665. 1899.	658°—710°
Falk, K. G., *Journ. Amer. Chem. Soc.*, xxviii, 1517: xxix, 1536. 1906-7.	514°—540°
Dixon, H. B., and H. F. Coward., *Journ. Chem. Soc.*, xcv, 514. 1909.	580°—590°

The above work has been carried out mainly with a view to the theoretical study of the subject, and the nature of the apparatus required, and the manner of conducting the experiments have not allowed the adoption of these methods for the rapid determinations necessary for technical work, and have also prevented the accumulation of large tables of results which might indicate the relation of ignition-point to chemical constitution.

In 1913, Holm§ roughly determined ignition-points of a large

* *Journ. Chem. Soc.*, cxv, 1003. 1917.
† *Journ. Chem. Soc.*, cxv, 1248. 1919.
‡ *loc. cit.*
§ *Zeitschr. angew. Chem.*, xxvi, 273. 1913.

variety of substances by employing an electrically-heated vertical-tube furnace, the apparatus being arranged as follows:

In the central heating-space of a Heraeus tube-oven, a glazed porcelain crucible lid is placed upside down on an axially disposed porcelain tube. On the lid is the naked junction-point of a platinum-platinum-rhodium element, connected with a galvanometer. The lid and heating-space can be maintained at the same temperature, and a slow current of air passes through the apparatus. When experimenting with gases a thin porcelain tube opening 1-2 mm. over the lid leads in the gas, at a rate sufficient to feed a flame between the size of a pea and a bean. The gas is admitted at each 10° difference in temperature. When a flame or explosion is observed, the existing temperature is taken as that of the ignition-point. When examining liquids, a burette is placed with its opening vertically over the lid, and a drop is allowed to fall at each 10° difference in temperature. The flame is sometimes from 2 to 3 seconds before it appears. The actual temperature is taken as the ignition-point. With solids, a knife-pointful in powder is sprinked on the lid, and the temperature of glow noted. This is often delayed from 5 to 10 seconds. The apparatus was used for the determination of ignition-points of solids, liquids and gases.

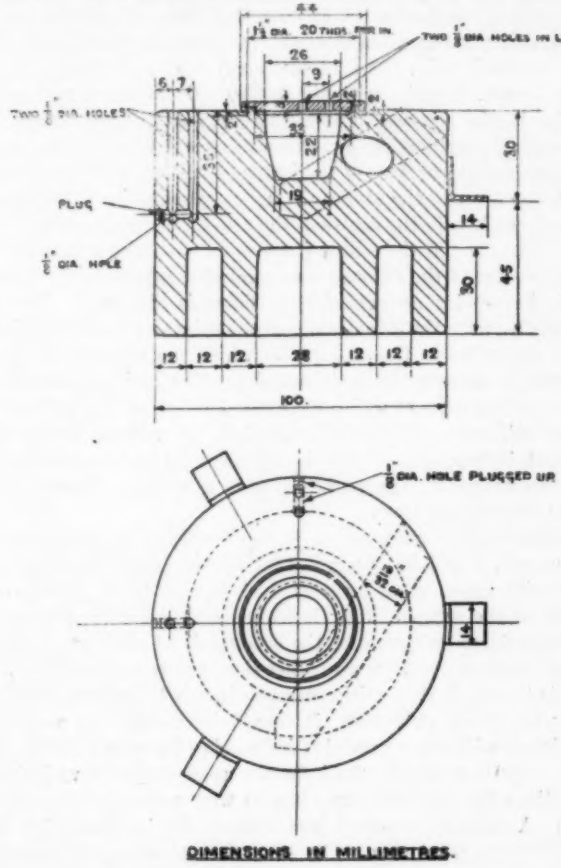
Constam and Schläpfer devised a rapid means of determining the ignition-point of liquids fuel. Particulars of their method were published in their paper* together with the results of tests on a large number of liquid fuels. The apparatus used by Constam and Schläpfer consisted of a small platinum crucible placed in a larger crucible, the intervening space being filled with sand. No means of preheating the incoming air or oxygen were employed. The temperature was measured by a platinum-platinum-iridium thermo-couple, the junction of which was situated inside the crucible close to the base. The results obtained by this method were not very regular, the experimenters concluding that the error was ± 30°.

In 1917 the writer published a paper†, describing experiments with another form of ignition-tester particularly designed for use with liquid fuels. This instrument has since been slightly modified, and the most convenient type is that shown in Fig 20.

The instrument consists of a diffusion-block of steel or cast iron 100 mm. in diam. and 75 mm. in depth. The base has been turned in a lathe in deep grooves in order to present greater heating-surface to the burner-flame. In the centre of the upper surface is a hole machined to fit exactly a platinum or nickel crucible. A cover

* *Zeitschr. Ver. deutsch. Ing.*, lvii, 1489. 1913.
† *Journ. Soc. Chem. Ind.*, xxxvi, 109.

screwed on the block protects the crucible from draughts. The cover is provided with two holes, one for the oxygen or air inlet, and the other for the admission of the substance to be tested. The



SPONTANEOUS IGNITIONMETER.

FIG. 20.

oxygen or air is passed from a container through holes drilled in the casting before entering the crucible, and is thereby preheated to the temperature of the diffusion-block. The block is provided with a

hole to fit the stem of the thermo-couple or resistance-pyrometer used to indicate the temperature of the instrument.

The method of operation when determining values in oxygen is to pass the gas into the crucible at the rate of three bubbles per second. The quantity of oxygen is observed by means of a wash-bottle filled with sulphuric acid, the acid also serving as a drying agent. A potash-tower, in series with the wash-bottle, removes any carbon dioxide in the oxygen. Commercial oxygen from cylinders was employed throughout the experiments, except when air was used.

When the temperature of the instrument is constant at a desired point, one drop of the substance under examination is introduced through the hole in the centre of the cover, and falls on the bottom of the crucible. If the temperature of the instrument is above the ignition-point of the substance an explosion takes place; if below the ignition-point no explosion or flame is observed. The time elapsing between the introduction of the substance and the explosion varies according to the amount by which the temperature of the instrument exceeds the ignition-point. The ignition-point is the lowest temperature at which the explosion follows the introduction of the substance. The results obtained by various operators on different instruments of the same design on the same substance agree to within 3°, except in the case of certain mixtures which shall be mentioned later.

In the method employed as in the foregoing description of the instrument, it will be observed that all the conditions have been arbitrarily fixed. One drop of fuel is employed. The rate of supply of the oxygen or air is stipulated. All dimensions of the instrument are defined, and the crucible is of platinum or nickel. If the results are to have any other than purely comparative value, that is to say, if the ignition-temperature is to indicate some true property of the substance, it should be possible to vary these conditions without appreciably influencing the results of the test.

In order to ascertain the influence upon results of variations in conditions the following experiments were made.

(*a*) A sample of petrol was tested, the ignition-point being found in the usual way. The same sample was again examined, but two drops of fuel were employed for each trial instead of one drop. The result was the same as when using one drop. Three drops of petrol were used in a further test, and the ignition-point was found to remain the same. When using three drops charge, the sound of the explosion was more muffled (less sharp) than when using the smaller charge of petrol. Similar tests using very small charges of petrol showed that the quantity of the substance used

could be varied within large limits without appreciably affecting the observed ignition-point.

A similar series of tests in which lubricating oil was employed instead of petrol also indicated that the amount of substance employed for test could be widely varied without influencing the results obtained.

In addition, series of tests were made in which the interval of time between the insertion of the charge and the explosion was measured by means of a stop watch. In these series one and two drops were introduced at various temperatures to note if any effect was produced. The interval between the insertion of charge and the explosion has been named the "wait period" in all such tests.

Test on Sample of Petrol.

Ignition-point 284½°. Platinum crucible used. 3 bubbles oxygen per second.

Temperature of Meter.	"Wait period."	Quantity of charge.
284½°	25 secs.	1 drop.
287½°	14 „	1 „
289°	12½ „	2 drops.
291°	11 „	1 drop.
293°	9·2 „	1 „
295½°	7 „	1 „
299°	5·8 „	1 „
305°	4 „	1 „
310°	3·2 „	1 „
316°	1·6 „	1 „
320°	1·4 „	1 „

Test on the same Sample of Petrol.

Observed ignition point 284°. Platinum crucible used. 3 bubbles oxygen per second.

Temperature of Meter.	"Wait period."	Quantity of charge.
284°	38 secs.	2 drops.
288½°	18 „	2 „
289½°	15 „	2 „
291½°	11 „	2 „
293°	9½ „	2 „
295°	7½ „	2 „
297°	6½ „	2 „
299°	6 „	2 „
300°	6 „	2 „

Temperature of Meter.	"Wait period."	Quantity of charge.
301°	4½ secs.	1 drop.
303°	5 „	2 drops.
304°	4½ „	1 drop.
304½°	4 „	1 „
307°	2·8 „	1 „
310°	2·8 „	1 „

The above two series of tests indicate that the quantity of charge does not substantially affect the result.

(*b*) Numerous tests were made in which the rate of oxygen-supply was varied, and it was found that this did not affect the ignition-point. If the supply be greatly reduced, as to less than 1 bubble per second, it is necessary to allow a pause of about two minutes between the tests to allow of the replenishing of the atmosphere inside the crucible, as otherwise the substance may refuse to ignite even when above the ignition-temperature.

(*c*) In addition to trials in which an atmosphere of oxygen was employed, many tests were made using air, and a series of trials with oxygen-carbon dioxide mixtures was also undertaken.

It was found that when employing an atmosphere of air the results were not so nearly concordant as with oxygen. The majority of the values in air (obtained by testing a great variety of hydrocarbon liquids) were from 80° to 200° higher than the ignition-points in oxygen. Commercial turpentine was peculiar in that it yielded the same result in both atmospheres (275°). The use of air necessitated the frequent cleaning of the crucible, as a carbonaceous deposit was liable to be formed. As the investigations were primarily conducted with a view to solving questions concerning internal-combustion engine design, it was considered that an atmosphere of oxygen more closely approached the conditions existing in the engine, where the air is raised to a considerable pressure, than would the employment of air at normal pressure in the ignition meter. It was assumed that as the concentration of oxygen in compressed air (at engine pressures) more closely approaches that of pure oxygen at normal pressure than that of air at normal pressure, it would be preferable to employ oxygen instead of air in the experiments. In any case the values are only to be considered as relative when applied to questions of engine design.

Repeated trials on standard samples of petrol and ethyl ether showed that variations of barometric pressure did not appreciably influence the results obtained from the ignition meter.

As the combustion of organic substances would leave an atmos-

phere of carbon dioxide in the crucible, it was decided to determine the influence of various proportions of carbon dioxide mixed with the oxygen atmosphere upon the ignition-point. The substance used in these trials was Empire kerosene (specific gravity, ·782), and the following ignition-points were determined :—

Empire kerosene, specific gravity ·782. Platinum crucible used. Composition of atmosphere by volume.

Composition of Atmosphere by Volume per cent. Oxygen.	Carbon dioxide.	Observed Ignition-Point.
100	0	254°
97½	2½	259
95	5	252
92½	7½	255·5
90	10	258
85	15	259
80	20	259
75	25	257
70	30	258
65	35	259
60	40	259
55	45	260
50	50	260
45	55	260
40	60	260
35	65	259
30	70	261

Though the ignition-point was little affected by the composition of the atmosphere over the range taken for the above tests, the sound produced by the explosion was very considerably reduced by the addition of the carbon dioxide.

(*d*) It seemed probable that the material from which the crucible was made would affect the observed ignition-point on account of catalytic action. Several tests were therefore made to decide this point. It was assumed that the " wait period " or time-lag between the introduction of the substance and the explosion would probably be affected by the action of a catalyst, even if the ignition-point itself was not affected.

The following table shows the results obtained by trials using platinum, nickel, silica and porcelain crucibles, and also a series of figures obtained by dispensing entirely with the crucible, in which case the substance was immediately in contact with the steel diffusion block. The results given in the table are also shown graphically in fig. 21.

Substance tested "Sample Petrol" in each case.

Conditions: Three bubbles oxygen per second: One drop of substance taken.

The barometric pressure varied, as the tests were made on different days.

Crucible of platinum.		Nickel.		Silica.		Porcelain.		Bare steel block.	
Seconds.	Temp.	Seconds.	Temp.	Seconds.	Temp.	Seconds.	Temp.	Seconds.	Temp.
25	284½°	23	282°	20	279½°	18	284°	13	281°
14	287½°	14	286°	15	280°	13·6	285°	10	282°
11	291°	12	286½°	13·6	281½°	12	287°	8	283°
9·2	293°	10	288°	9	284°	10	289°	5·6	286°
7	295½°	10	288½°	9	286°	6·8	294°	4·2	292°
5·8	299°	7·6	291½°	6·4	287	7·2	296°	3·8	294°
4	305°	6·8	294°	6	289°	4·2	300°	3	301°
3·2	310°	6	298°	5·8	290°	4	301°	2·2	307°
1·6	316°	5	300°	4·4	295°	3·6	303°	1·8	310°
1·4	320°	4·6	302°	3·4	300°	3·4	306°	—	—
—	—	4·2	302½°	3	305°	3	310°	—	—
—	—	4·2	303°	2·4	308°	3	312°	—	—
—	—	3·6	304°	2·4	310°	—	—	—	—
—	—	3·6	307°	2	312°	—	—	—	—
—	—	3	309°	—	—	—	—	—	—
—	—	2·8	310°	—	—	—	—	—	—
—	—	2·8	311°	—	—	—	—	—	—
Ignition-point 284½°		Ignition-point 282°		Ignition-point 279½°		Ignition-point 284°		Ignition-point 281°	

In view of the trials having been conducted on different days and therefore under varying atmospheric pressures, and possibly under slight variations of other conditions, it was considered that the different readings were very close, and that any catalytic action which had taken place did not affect the results by greater amounts than were covered by the term "experimental error."

(*e*) Numerous tests were made in order to ensure that the recorded temperatures should be as close as possible to the actual temperature of the crucible. Temperature-readings by thermometers immersed in mercury in a porcelain crucible inside the cavity in the block were found to be in agreement with the pyrometer readings up to such temperatures as thermometers were capable of

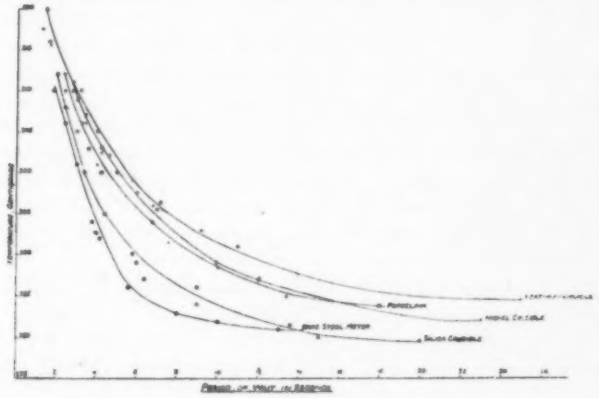


FIG. 21.

recording. Readings were also obtained by a very fine thermo-couple, the junction of which touched the base of the crucible. These were also in agreement with the readings of the pyrometer situated in the normal position.

In many of the low-temperature tests (below 350°) a standard nitrogen-filled high-temperature mercurial thermometer was used. For the higher temperatures (350° to 700°) a base-metal thermo-couple was employed in the earlier experiments, but later this instrument was abandoned in favour of a Whipple resistance-pyrometer, which was much more sensitive, and dispensed with the cold-junction corrections which are necessary when using pyrometers of the thermo-couple type. The earlier experiments were repeated

in order that all the results might possess the greater accuracy obtainable from the resistance-pyrometer.

(*f*) The results of determinations of the temperatures of spontaneous ignition of gaseous mixtures obtained by various experimenters have shown the greatest divergence, and the irregularity in the temperatures recorded may largely be caused by the variation of the several conditions, principally of the time interval during which the combustible mixture was exposed to the action of heat.

McDavid* attempts as far as is practically possible to eliminate the time factor. In his experiments the explosive mixture is contained in a soap bubble which is brought into contact with a heated coil or other heated body.

It appears from the foregoing experiments regarding the time interval or "wait period," that with liquid fuels the ignition-point is a function of the period during which the mixture is exposed to the heating-surface, and as a definite temperature is noted, below which the mixture refuses to ignite however long it is maintained at any lower temperature, it appears to be more satisfactory to take this temperature as the ignition-point than one at which the time of exposure is abbreviated. It appears that the most reliable reading would be obtained by producing the curve of "wait period" against temperature until the temperature-value became constant (i.e., when the "wait period" would be infinite).

Though there is little doubt that silent combustion must take place to some extent below the ignition-point, yet it was impossible to detect carbon dioxide in samples of gas withdrawn from the crucible during trials at 5° below the ignition-point of fuels under test.

As the entire investigation was undertaken with a view to testing the relationship between the temperatures of spontaneous ignition of liquid fuels, and the compression-pressures permissible in internal-combustion engines when burning these fuels, the substances tested were also entirely confined to commercial liquid fuels and to certain kindred substances which happened to have some bearing on the subject.

The following is a list of the observed spontaneous ignition-points of the substances tested †:

* *Op. cit.*, p. 1004.

† See *Journ. Soc. Chem. Ind.*, xxxvi, 109.

TEMPERATURES OF SPONTANEOUS IGNITION.

Description.	Specific gravity.	Ignition-temperature in oxygen.	Ignition temperature in air.	Difference.
Petroleum Distillates.				
Pratt's Perfection Spirit No. 1.	·710	272°	383°	111°
Petrol (Mex)	·718	279°	361°	82°
Pratt's Spirit No. 2	·724	270°	371°	101°
Taxibus Spirit (Anglo-American Oil Co., Ltd.)..	·729	272°	390°	118°
Paraffin Oil (Anglo-American Oil Co., Ltd.)	·807	251°	—	—
Petrolite Kerosene	·814	251·5°	432°	180·5°
Empire Paraffin	·782	253°	395°	142°
Petrol (Anglo-American Oil Co., Ltd.)	·785	—	392°	—
Lamp Oil (Anglo-American Oil Co., Ltd.)	·787	—	367°	—
Gas Oil (Anglo-American Oil Co., Ltd.)	—	254°	358°	104°
Petroleum (Crude and Residue).				
Crude Petroleum (Egypt) ..	·851	260°	—	—
Digboi Oil (Assam)	·890	261°	384°	123°
Anglo-Persian Oil Co's Oil ..	·894	254°	408°	154°
Crude Petroleum (Texas) ..	·895	256°	387°	131°
Anglo-American Fuel Oil ..	·900	269°	430°	161°
Anglo-Mexican Oil	·908	259·5°	417°	157·5°
Crude Petroleum (Texas) ..	·936	268·5°	416°	147·5°
Crude Petroleum (Borneo) ..	·939	269°	380°	111°
Mexican Fuel Oil	·948	259·5°	424°	164·5°
Crude Petroleum (Mexican) ..	·949	258°	425°	167°
Crude Petroleum (Trinidad) ..	·950	274°	424°	150°
Crude Petroleum (California) ..	·952	264°	—	—
Venezuelan Petroleum ..	·955	275°	429°	154°
Crude Petroleum (California) ..	·961	262°	420°	158°
Shale Oils.				
Oil Engine Oil (Broxburn Oil Co.)	·768	253°	333°	80°
Lighthouse Oil (Broxburn Oil Co.)	·803	251°	322°	71°

TEMPERATURES OF SPONTANEOUS IGNITION—*continued.*

Description.	Specific gravity.	Ignition-temperature in oxygen.	Ignition-temperature in air.	Difference.
Tar Distillates.				
Xylol (commercial)	·860	484°	—	—
Toluol, 90%	·863	516°	—	—
Benzol, 100%	·875	566°	—	—
Premier Tarless Tar Oil ..	·992	349°	—	—
Creosote Oil (Hardman & Holden)	1·010	415°	—	—
Tar Oil	—	465°	—	—
Water Gas Tar Creosote (Stainsby & Lyons)	1·036	473°	—	—
Coke Oven Tar Oil (Simon Carvès)	1·046	478°	—	—
Creosote	—	497°	—	—
Coke Oven Creosote	—	452°	—	—
Blast Furnace Tar Creosote ..	—	284°	—	—
Tars.				
Tar, Product of low temperature carbonisation..	·987	307°	508°	201°
C.W.G. Tar (Stockport Gas Works)	1·074	464°	—	—
Oil Gas Tar (Beckton) ..	1·077	415°	—	—
Horizontal Retort Tar (Heywood Gas Works)	1·114	445°	—	—
Horizontal Retort Tar (Stockport Gas Works)	1·123	454°	—	—
Coke Oven Tar (Simon Carvès)	1·132	494°	—	—
Coke Oven Tar (Coppée Co.)	1·140	488°	—	—
Coke Oven Tar (Koppers Type Ovens)	1·145	495°	—	—
Blast Furnace Tar (Carlton Iron Works)	1·172	498°	—	—
Blast Furnace Tar (Wm. Baird & Co.)	—	410°	—	—
Miscellaneous.				
Ethyl Alcohol	·817	395°	518°	123°
Turpentine	·842	275°	275°	—
Lubricating Oil A	·875	265·5°	405°	139·5°

TEMPERATURES OF SPONTANEOUS IGNITION—*continued.*

Description.	Specific gravity.	Ignition-temperature in oxygen.	Ignition-temperature in air.	Difference.
Miscellaneous—continued.				
Lubricating Oil B	·894	265·5°	401°	135·5°
Whale Oil	·921	273°	470°	197°
Ether (Methylated)	·730	190°	347°	157°
Paraffin Wax	—	245°	—	—
Naphthalene (resublimed) ..	—	402°	—	—
"Free Carbon" from Tar ..	—	348°	—	—
Asphaltum from Petroleum ..	—	260°	—	—
Paraldehyde	—	210°	—	—
Carbon Disulphide	—	119°	—	—
Nitrobenzene	—	432°	—	—
Aniline	—	550°	—	—
Methylated Spirit	—	524°	—	—
Wood Naphtha	—	506°	—	—
Benzene (crystallizable) ..	—	620°	—	—
Pure Toluene	—	596°	—	—
Normal Hexane	—	287°	—	—
Heptane	—	281°	—	—

As the ignition-points of liquids, obtained by the writer, were very much lower than the observed ignition-points of gases published by other experimenters, it was decided to test a gas under conditions agreeing as closely as possible with those adopted when testing liquids.

For the purpose of these trials, the cover and oxygen supply connections were removed from the instrument, and the combustible gas under investigation was passed through the preheating duct, after which it emerged from a jet 1½ mm. in diameter. The jet was situated one mm. from the base of the crucible. Three or four bubbles of the gas were passed into the crucible intermittently at every 1° rise in temperature of the diffusion-block, and the lowest temperature at which ignition took place was noted. It was observed that ignition was uncertain until the temperature of the diffusion-block rose 4° above the lowest temperature at which ignition was observed to take place. The ignition-points given are the lowest temperatures.

Hydrogen generated from pure zinc and hydrochloric acid, after washing in distilled water was employed. The hydrogen was not dried, as it was considered impossible to entirely remove water

vapour from the vicinity of the experiment. The following results were obtained :—

HYDROGEN IN AIR.

Material of Crucible.	Observed Ignition-Point.
Porcelain	686°
Nickel	619°
Silica	678°

It may be noted that the observed temperatures when a nickel crucible was employed were considerably lower than the other readings. This was undoubtedly caused by silent combustion below the ignition-point, and consequent local heating of the crucible surface. The nickel crucible was covered with oxide, and when the current of hydrogen came in contact with this surface the film of oxide provided the necessary conditions for silent combustion, and the local rise in temperature could be clearly discerned with the eye. No such local heating could be observed on the smooth surfaces of the porcelain and the silica crucibles, but doubtless silent combustion must take place, though to a much lesser extent.

By passing oxygen through a second preheating duct, and arranging the jet of hot oxygen to impinge on the crucible at the same point as the hydrogen, it was possible to obtain a rough value for the ignition-point of an oxygen-hydrogen mixture. The oxygen was continuously passed into the instrument at a rate of 3 bubbles per second, the hydrogen being intermittently introduced at intervals of 30 seconds.

The ignition-points recorded in three experiments, using a silica crucible, were 678°, 680° and 677° respectively.

From the foregoing lists of ignition-points the following generalisations have been formed (see *Journ. Soc. Chem. Ind.*, xxxvi 109. 1917).

(1) Compounds containing simple molecules have higher ignition-points than compounds of the same series containing more complex molecules.

(2) The ignition-points of aromatic compounds are much higher than those of aliphatic compounds.

(3) Unsaturated hydrocarbons have slightly lower ignition-points than the corresponding saturated hydrocarbons.

(4) Ignition-points observed in air are higher than those observed in oxygen.

The theory that the ignition-point was dependent upon the hydrogen content (high hydrogen content giving low ignition-point) does not always hold true, though it roughly applies to mixtures of

aliphatic and aromatic hydrocarbons. It is however incorrect when applied to the petroleum distillates, as is observable from the following figures :—

Substance.	Ignition-point.	Approximate percentage of hydrogen.
Petrol	270° to 279°	15·5
Kerosene.. ..	251° to 254°	14·0
Paraffin wax ..	245°	13·5

Nor does it apply to the pure substances benzol and naphthalene :

Substance.	Ignition-point.	Percentage of hydrogen.
Pure benzol ..	620°	7·7
Pure naphthalene	402°	6·3

The foregoing rules regarding molecular complexity are what might be expected. The ignition-point is of particular theoretical interest as being, to some extent, a measure of the stability of a compound.

The substances possessing remarkably low ignition-points are in each case compounds which readily undergo an exothermic reaction to yield a product of partial oxidation, as shown :—

Substance.	Ignition-point.	Product of partial oxidation.
Paraldehyde	210° ..	Acetic acid
Carbon disulphide.. ..	119° ..	Carbon oxysulphide
Ether	190° ..	Formic acid

With these substances it is evident that the partial oxidation generates sufficient heat to raise the mixture to temperatures well in excess of that of the diffusion-block.

Ignition-Points of Binary Mixtures.

It was considered desirable to investigate the ignition-points of various mixtures of two fuels, the object being primarily to investigate the relationship between the ignition-point of a mixture and those of its constituents. The following series of tests were made, the results being given in both tabular and graphic form :—

(1) Ignition-points of mixtures of kerosene and creosote.

Creosote per cent.	Kerosene per cent.	Ignition-point.
100	0	336°
90	10	308°
80	20	305°
70	30	296°
60	40	286°

Creosote per cent.	Kerosene per cent.	Ignition-point
50	50	282°
40	60	276°
30	70	270°
20	80	265°
10	90	261°
0	100	253°

(See No. 4, Fig. 22).

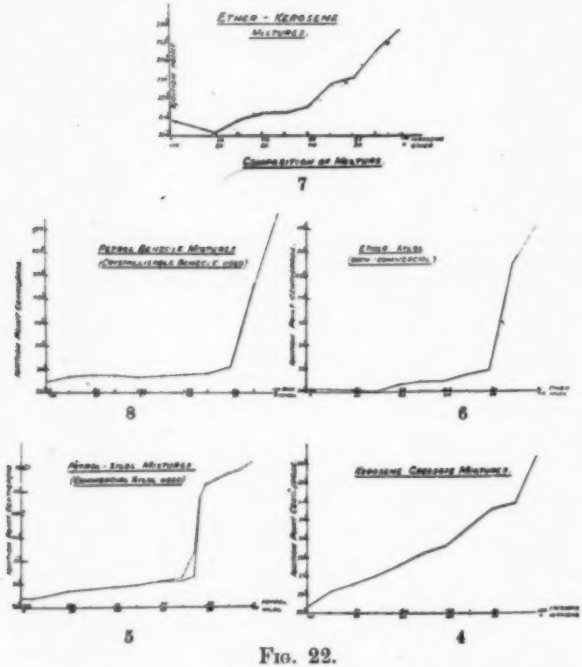


FIG. 22.

(2) Ignition-points of mixtures of xylol and petrol of spec. grav. ·718.

Xylol per cent.	Petrol per cent.	Ignition-point.
100	0	555·5°
95	5	546°
90	10	539°
80	20	512°
77½	22½	487°

Xylol per cent.	Petrol per cent.	Ignition-point.
75	25	313° to 367°
72½	27½	346°
70	30	317°
60	40	308°
50	50	297°
40	60	294°
30	70	290°
20	80	286°
10	90	275°
5	95	271°
0	100	270°

(See No. 5, Fig. 22).

Ignition-points of mixtures of xylol and ether (commercial).

Xylol per cent.	Ether per cent.	Ignition-point.
100	0	555°
90	10	475°
80	20	246°
70	30	235°
60	40	221°
50	50	221°
40	60	215°
30	70	200°
20	80	202·5°
10	90	204°
0	100	206°

(See No. 6, Fig. 22).

Ignition-points of mixtures of kerosene and ether.

Kerosene per cent.	Ether per cent.	Ignition-point.
100	0	256°
90	10	245°
80	20	230°
70	30	227°
60	40	215°
50	50	212°
40	60	212°
30	70	208°
20	80	202°
10	90	205°
0	100	208°

(See No. 7, Fig. 22).

Ignition-points of mixtures of benzol (crystallizable) and petrol.

Benzol per cent.	Petrol per cent.	Ignition-point.
100	0	630°
90	10	481°
80	20	303°
70	30	290°
60	40	287°
50	50	284°
40	60	281°
30	70	286°
20	80	280°
10	90	283°
0	100	272°

(See No. 8 Fig. 22).

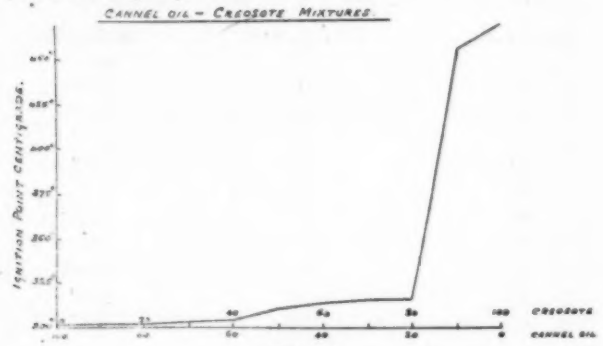


FIG. 23.

Ignition-points of mixtures of "cannel oil" and creosote.

Creosote per cent.	Cannel oil per cent.	Ignition-point.
100	0	468°
90	10	455°
80	20	316°
70	30	316°
60	40	314°
50	50	311°
40	60	304°
30	70	303°
20	80	302°
10	90	302°
0	100	302°

(See Fig. 23).

Ignition-points of mixtures of "cannel oil" and Mexican petroleum fuel oil, spec. grav. ·910.

Cannel oil per cent.	Petroleum per cent.	Ignition-point.
100	0	302°
90	10	292°
80	20	283°
70	30	272°
60	40	271°
50	50	271°
40	60	270°
30	70	269°
20	80	269°
10	90	261°
0	100	261°

(See Fig. 24).

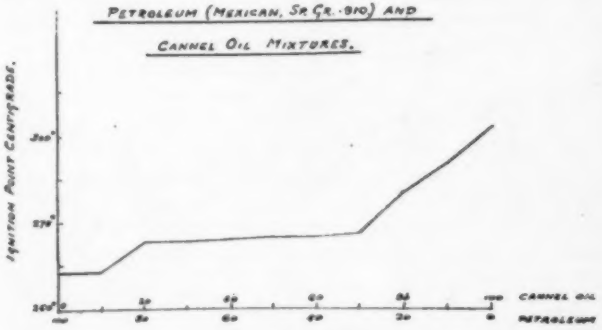


FIG. 24.

From the curves of ignition-points of the mixtures given, and from various incomplete portions of other curves which the author has investigated, it may be observed that the curves are generally of the type shown in Fig. 25.

A small addition of the constituent of higher ignition-point has little effect on the ignition-point of the mixture in which the constituent of lower ignition-point greatly predominates. Similarly a small amount of the constituent of lower ignition-point has little effect on the ignition-point of a mixture in which the constituent of higher ignition-point greatly predominates.

It is notable that the experimental error present when testing the mixtures whose composition corresponds with the steep portions

of the curves are much greater than is the case with mixtures of other composition. In fact if experimental error be shown on the curves the result is as shown in Fig. 26.

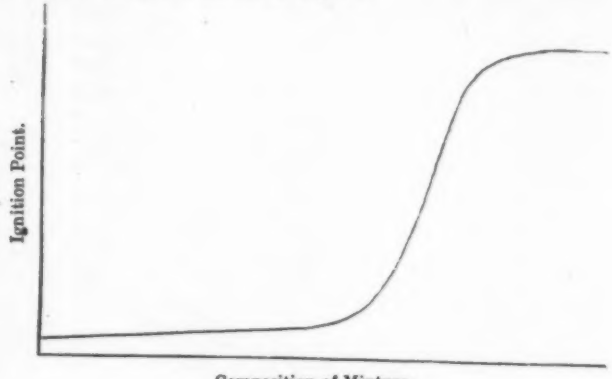


FIG. 25.

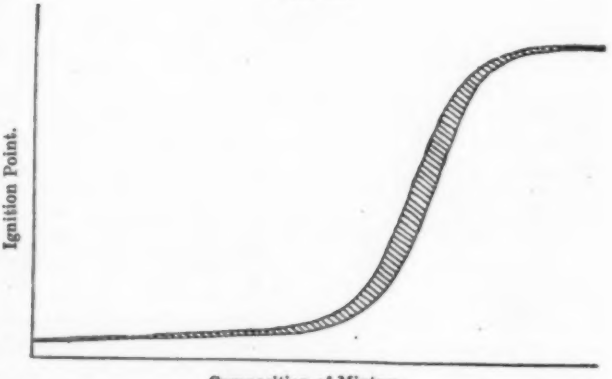


FIG. 26.

THE BEARING OF THE IGNITION-POINT OF FUELS UPON THE COMPRESSION PRESSURE OF INTERNAL-COMBUSTION ENGINES.

In internal-combustion engines, whether of the two-stroke or four-stroke cycle, the theoretical thermal efficiency is dependent upon the compression-ratio. This applies to engines operating both upon the constant-volume and the constant-pressure cycles.

The relationship between the compression-ratio and the theoretical thermal efficiency follows certain well-known laws of thermodynamics.

As the volumetric efficiency is not always a constant value, it is more accurate for the present purpose to deal with the relationship between the compression-pressure and the thermal efficiency. Graphs showing the dependence of both the theoretical and the practical thermal efficiency upon the compression-pressure of internal-combustion engines are shown in Fig. 27 (see *The Engineer*, 1917, p. 561).

From the foregoing it follows that it is advisable to adopt the highest compression-pressure possible. The increase of compression-pressure however, is limited in engines operating on the constant-volume cycle by the temperature of the explosive mixture exceeding the temperature of spontaneous ignition of the charge. If the temperature of compression is higher than the ignition-point of the fuel, pre-ignition or early firing occurs before the engine piston has reached the inner dead centre, and " knocking," together with loss of power and overheating, results.

The maximum compression permissible in an engine operating on the constant-volume cycle is therefore limited by the ignition-point of the fuel. Engines of the Diesel type operating on the constant-pressure cycle are dependent upon the spontaneous ignition of the fuel, as no other means of ignition are provided (Semi-Diesel or " hot-bulb " engines are not to be included in this class). It is therefore essential that the compression-pressure of a Diesel engine shall yield such a temperature of compression as shall exceed the ignition-temperature of the fuel.

The temperature resulting from the compression of a gas under adiabatic conditions may be calculated from the formula :—

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right) \frac{n-1}{n}$$

where : T_1 and T_2 are initial and final temperatures absolute respectively, and P_1 and P_2 are initial and final pressures absolute.

For air, under adiabatic conditions, the value n (the ratio between specific heat at constant volume and at constant pressure) is equal to 1·408, but as the conditions in internal-combustion engines are not perfectly adiabatic, the value n usually approximates 1·35.

Now, assuming the temperature of the induction gas to be 30°, we may construct, by means of the above formula, a graph, from which the temperature of the charge at any given compression-pressure may be determined. Such a curve is shown in Fig. 28 as the curve E F. With a perfectly-designed petrol engine, in which

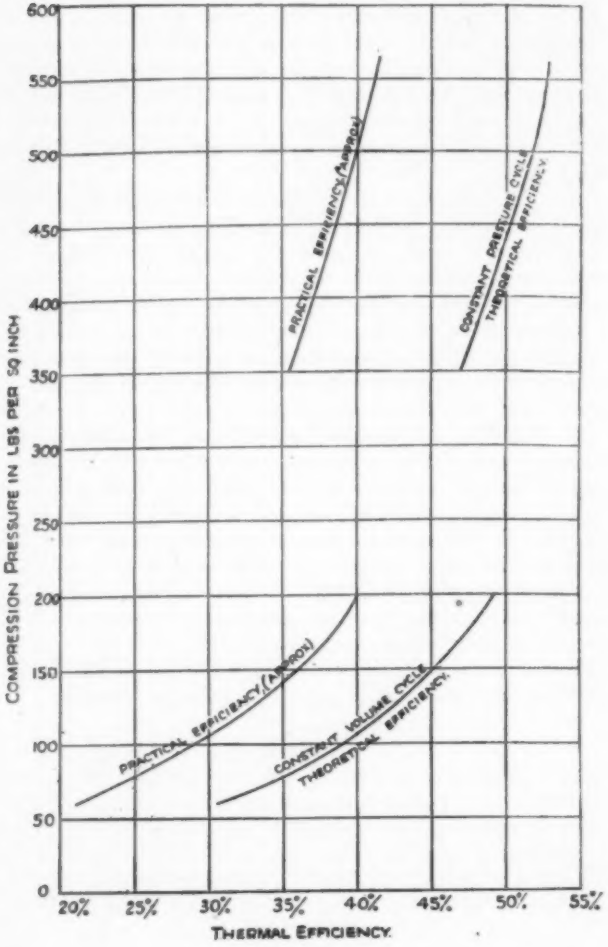

COMPRESSION PRESSURE IN LBS PER SQ INCH
600
550
500
450
400
350
300
250
200
150
100
50
0
20%
25%
30%
35%
40%
45%
50%
55%
THERMAL EFFICIENCY
PRACTICAL EFFICIENCY (APPROX)
CONSTANT PRESSURE CYCLE
THEORETICAL EFFICIENCY
PRACTICAL EFFICIENCY (APPROX)
CONSTANT VOLUME CYCLE
THEORETICAL EFFICIENCY

FIG. 27.

no local high temperatures exist in the combustion-space, it would be possible to state, knowing the ignition-point of any fuel, that, in order to prevent pre-ignition, the compression must be such that when plotted against the ignition-point of fuel, the point obtained would lie somewhere beneath the curve E F. This latter curve would thus indicate the maximum limit of compression corresponding to any ignition-point on the axis O X. From considerations of a similar nature, it follows that the curve E F, for engines working on the Diesel cycle, represents the minimum compression-pressure admissible for the burning of any fuel the ignition-point of which is found on the line O X.

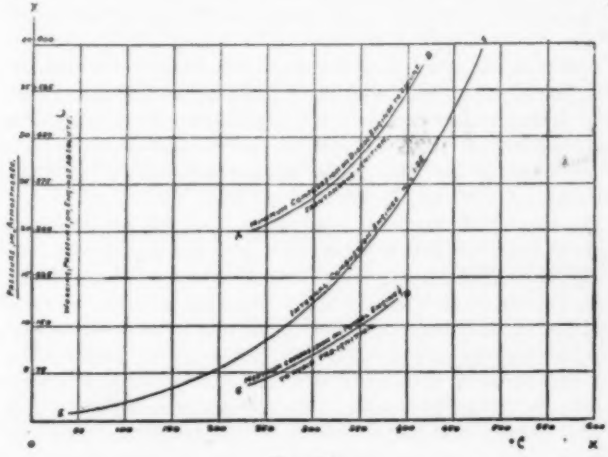


FIG. 28.

The conditions of practice, however, do not wholly correspond with the theoretical assumptions on which this demonstration is based. The ignition-temperatures observed on the instrument, using oxygen, at normal pressure, are not identical with those which might be obtained under cylinder-conditions, which include pressure and the presence of air, with some amount of residual exhaust gases. It seems possible that the temperature of spontaneous ignition, either in air or oxygen, may prove to be a function of the pressure, though the experiments of Dixon and Coward indicate that increased pressure does not greatly influence the temperature of ignition. In the case of petrol engines local high temperatures will inevitably exist in the combustion-space, what-

ever be the design of the engine, and in Diesel engines we must reckon with the cooling effect of the blast air on the gases in the combustion-space at the period of injection. On a petrol engine, firing immediately in advance of the inner dead centre would not be regarded as pre-ignition, as the correct time of firing at high speeds is very considerably in advance of that point. At low speeds when the spark advance is less, engines are more sensitive to pre-ignition. Other varying factors exert their influence, but the forementioned are the most important.

Though the curve E F does not represent the maximum and minimum compression permissible under working conditions in constant-volume and constant-pressure cycle engines respectively, it is possible to construct curves showing the practical limits of these values.

Admitting the assumption that the ignition-point of a fuel under cylinder-conditions will be a continuous function of the ignition-point determined by experiment, it is possible to plot a curve of the ignition-point of the fuel against the maximum compression-pressure, which has been found to give satisfactory working in practice in a constant-volume cycle engine.

The curve C D has been constructed from the results of trials made by numerous authorities upon various standard grades of fuel, the ignition-points of which have been determined in the tester.

By experimental determination of the ignition-points of various oils, and an examination of their behaviour in a Diesel engine at various compression-pressures, the necessary data were obtained, and the curve A B showing the minimum compression-pressure possible to obtain satisfactory running was constructed.

It is usually desirable to run Diesel engines at the lowest compression-pressure which will give satisfactory running on any given fuel, as higher pressures than the usual 450 to 500 lbs. per square inch cause increased piston-ring friction and stress on the materials of which the engine is constructed, which disadvantages more than counterbalance the theoretical gain in efficiency. Hence it is advisable, when adjusting compression-pressures for an engine to run on any particular fuel, to employ such compressions as shall lie upon, or only slightly above the curve A B, when plotted against the ignition-point of the fuel.

As it was conceivable that considerable advantage in efficiency might be gained by mixing the commercial fuels used in automobile and aircraft engines, curves were prepared showing the ignition-points of several such mixtures. As it is not practical to vary the compression of car engines to suit each particular grade of fuel, and

as a large portion of the available power is lost when burning fuels of high ignition-point, e.g., benzol and alcohol, in engines designed principally for petrol, a fuel of low ignition-point, it would be advantageous to mix the fuels in such proportions as to yield a standard ignition-point, in order to allow the compression of engines to be raised to such a pressure as would utilise the fuel most economically.

DISCUSSION.

The President, in proposing a hearty vote of thanks to the author for his paper, said he thought what he had said at the beginning as to the subject being rather a profound one had been borne out by what Mr. Moore had said. It did seem, however, from the concluding paragraph of the paper that research had led to considerable practical results as to the mixture of fuels, and perhaps the members would hear from some of their scientific friends whether there was any particular scientific theory that was either constructed upon those experiments, or substantiated by them.

Mr. J. L. Chaloner exhibited a slide showing the work which had been carried out originally in connection with the relationship between the ignition-point and oil-engine fuels. The slide showed the ignition-apparatus constructed by Rieppel who, some 17 years ago, thought that the ignition-point might have some bearing on the suitability of the fuel. This was the first ignition-meter for investigating fuel oils, and Rieppel intended to approach as nearly as possible to practical conditions under which the ignition-point may possibly effect the thermal conditions generally. He employed a bomb of 1 litre capacity which was placed in a suitable vessel to retain a pre-determined temperature. In the cover of the bomb were three connections. The first led to a pressure-gauge to record the change in pressure with a rise of temperature, the second to a drum which had a surface speed of 3 metres per second, recording the relationship between rise of pressure and time, and the third connection to a compressed-air reservoir provided with a stop-valve by means of which a certain amount of air under a definite pressure could be introduced into the bomb. At the bottom of the bomb was a small crucible in which was placed a minute quantity of oil. A definite quantity of air was introduced to create turbulence, and give a desired air-excess coefficient. An experiment was, therefore, carried out under specific conditions of temperature, pressure and

air-excess coefficient which in the opinion of the speaker are the governing factors in the subject under discussion. Rieppel's experiments were unsuccessful and were abandoned, owing to the fact that he could never attain the desired temperatures and pressures, and keep all the joints tight.

The second arrangement, which is described by Mr. Moore in the paper, refers to Holm's apparatus, and here we have represented the first attempt of studying the effect of a globule of oil dropping on to a heated crucible-cover. The bottom of the central tube was 2 mm. above the crucible-cover, and for some reason or another Holm specified that as being the best position. He did not specify any particular distance between the crucible-cover and the end of his burette, so that one might get an idea of the distance the drop of oil would have to fall, but he (the speaker) presumed that this must have been a definite distance in order to give uniform results.

The next slide represented an arrangement, also described by Mr. Moore, and known as the "Constam and Schläpfer" apparatus. The members would no doubt be able to follow the drawing from Mr. Moore's description. Here again the oil was allowed to drop on to the crucible, and the distance between the bottom of the pyrometer terminal and the crucible was 3 mm., whilst Schläpfer had pointed out that by varying the distance from 3 mm. to 10 mm. a difference of something like 10° on the galvanometer could be detected. The fact that these experimenters had specified the distance would indicate the sensitiveness of the instrument and the delicate adjustments which became necessary to obtain uniform results.

The slide had been exhibited for the purpose of recording to some extent the historical part of the subject with special reference to fuel oils.

He thought that Mr. Moore's paper brought out two important points, firstly that more ought to be known about the ignition-point of oils, and secondly if more were known it might be possible to establish some relationship between the ignition-point of an oil and its suitability for internal-combustion engines.

Dr. Ormandy remarked that the last speaker had stated that if something more were known about the chemical and physical reasons which underlay the very peculiar results which had been referred to by Mr. Moore and Mr. Chaloner, a better basis might be obtained on which to work, and that the matter would no longer be so empirical. However, up to date, as far as he (Dr. Ormandy) knew, no attempt had been made to publish any theory, or any

attempt at any theory, or any application of known theory, to give even a possible outline of an explanation. With the members' permission, he would attempt, at any rate, to propose a theory, which might or might not stand the test of time and proof, but which would serve as a basis for somebody else to work upon.

In the first place, of the things to be noticed in the results he would point out that dealing with the chain-compounds, that was, the paraffins, the total range of ignition-temperatures from benzol to a comparatively heavy paraffin was comparatively small. On the other hand, the difference in the spontaneous-ignition temperature, discovered thus empirically, between benzol and heavy creosote, for instance, was very considerable. The members were aware that vapour of petrol or benzol would not ignite under ordinary conditions in a mixture of oxygen or air, unless in contact with a platinum wire which was pretty nearly at white heat, or in the presence of an actual spark. Attempts to fix a minimum temperature at which that ignition would take place when the vapours were cold and an igniting body was suddenly placed into it (such as the experiments dealing with soap-bubbles and the like) showed that the end-results were tremendously influenced by the actual physical conditions under which those experiments were carried out. Thus, for instance, it made a difference of many degrees whether the ignited platinum wire was inserted in the bottom, or the middle, or at the top of the soap bubble containing the explosive mixture. It made a difference whether the platinum wire was used for the first time, or had got covered with a small amount of alkali salts from the soap which was being employed.

He would have to take the members into the realms of elementary chemistry for a moment. He would ask them to assume that they were dealing with pentane, because it was a well-known chemical substance of fairly simple constitution. They had in the crucible pentane vapour and oxygen. The chemical re-action was hastened when the molecules were in a state of more active movement, and the first question one would ask was, was it a sufficient explanation to say that the gases, that was, the pentane particles and the oxygen particles, were caused to move about more rapidly due to the actual heating by convection from the sides of the crucible? In other words, was it merely that the kinetic impacts of the particles had increased to such an extent that chemical combination took place? The answer, he thought, was absolutely and obviously in the negative, for the reason that the kinetic energy of a particle only increased at a very slow speed as the temperature rose, and it was known that at a temperature of 260°, for instance, petrol and

oxygen did not combine, and that at 270° they did combine under the conditions in question. An increase of 10° could only correspond to an increase in the kinetic energy of the particles of a very small amount, possibly 2 per cent., or at the outside 3 per cent.

It might be asked, Was it due to what was known as increase of inter-molecular energy? The calculated increase in inter-molecular energy was measured by the ratio of the specific heats at constant volume and pressure, and it was known that the increase of temperature produced a very small increase in inter-molecular energy, the increase being proportionate to the increase in absolute temperature; and in a case such as they were now considering there would be only 2 per cent. increase in the internal energy of the particles due to the actual heat from the sides of the vessel.

They had now more or less satisfied themselves that the combination could not take place merely because the particles were in more rapid motion, or the atoms within the molecules were in more rapid motion. What else remained? He would at that stage just take the members back for a moment to the consideration of an experiment which all of them in their early days of elementary chemistry must remember, namely, that a mixture of hydrogen and chlorine did not combine in the dark; they would not combine if they were heated up to a very considerable temperature; but they would combine instantaneously if they were exposed to radiation of short wave-lengths, that was, visible light. During recent years a great amount of work had been done on that influence of visible light, and it could only be assumed that in the ether radiations, which it was known carried energy (because a ray of light was known to exert a pressure, and could cause a vane to move) and that that energy was of such a character that it could cause chlorine to combine with oxygen. There was something inherently peculiar in light between certain wave-lengths. The members knew, further, that if they allowed strong white light to pass through a layer of chlorine, and then allowed it to pass on to a mixture of chlorine and hydrogen, no combination would take place. From that could be deduced the fact that the chlorine gas had absorbed certain peculiar vibrations or oscillations or radiations out of the white light, and when the remainder of the light passed on to the hydrogen and chlorine mixture, it could not cause any combination.

Was there any reason why that well-known photo-chemical effect of visible light and ultra-violet light should not be supposed to have an action at a lower temperature? They did know that any heated body gave out radiations. They knew, for instance,

that if one put one's hand near a kettle one could feel the heat radiations from it; one could even feel the heat radiations from an ordinary gas stove supplied with modern gas doled out at a high price. Consequently it was known that at the temperature of 270° or 580°, according to whether petrol or benzol was being dealt with, there were heat-waves being given out in the body of that crucible. If it could be assumed that something was happening similar to what happened with the well-known mixture of hydrogen and chlorine, they would interpret the position as follows. Dealing with petrol at a temperature of 270° Cent. there were certain heat radiations given off from the walls of the crucible, and the wave-lengths of these would vary over considerable range, but there would be a point of maximum energy, and this was found at somewhere in the neighbourhood of radiations having wave-length of $\frac{\text{A}}{1000}$ths of a mm.

If petrol is affected by a specific wave-length, one would expect to find that petrol vapour would show an absorption band at or about the point of the maximum radiation at the temperature of ignition. This was found to be the case.

The experiments carried out by Coblentz, and published in the Transactions of the Carnegie Institute at Washington, showed that with all the paraffins the maximum point of absorption is at about the wave-length of $\frac{\text{A}}{1000}$ths of a mm.

We had still to account for the fact that the heavier paraffins showed a slightly lower ignition-temperature than the lighter ones.

Coblentz's experiments showed that the absorption band widened as the molecular weight of the paraffins increased, and the greater width of the band pointed to the ability of the compound to absorb a wider range of heat radiations.

A cursory examination of the absorption spectra of the ring-compounds are in support of the general idea outlined above, but much more work will have to be done before the proposal thus put forward can be regarded in any way in the light of an explanation.

The speaker has taken the matter up, and hopes to report at some future meeting of the Society as to the outcome. He would say that there was nothing new in the theory, but only in its application. It was an application of Prof. Lewis' (of Liverpool) theory on Critical Energy Increments under the Einstein theory of Quanta. It struck him that in spite of the somewhat difficult nature of the explanation, he was justified in bringing it forward. It was in any case an interesting example of the possible value of abstruse and difficult experiments carried out at great expense, and which to the ordinary man in the street, and even to the

ordinary scientist, might appear almost a waste of time, whereas there was more than a possibility that the results of this work might in actual fact have a very immediate and direct bearing on subjects of the greatest practical interest.

Mr. W. MacNab said he had been brought into contact with the subject of spontaneous ignition of petrol by reason of two explosions which he had had in determining the calorific value of some petrol. He thought the instances were of a somewhat unusual nature, and he had brought the lid of the bomb with him so that the members could inspect it at the close of the meeting. It was that of a Berthelot bomb, and the procedure, when the explosion took place, had been as follows. About a gramme of petrol had been sucked into a little glass bulb, which had been sealed and placed at the bottom of the bomb. The cover had been screwed on and connected up with an oxygen cylinder, the intention being to run the pressure up to 25 atmospheres. Generally between 5 and 10 atmospheres a little click was heard owing to the breaking of the bulb. On one occasion the connections had been all opened, the oxygen had been going in, and between 5 and 10 atmospheres there had been quite a violent explosion, and a little copper tube which bent over, and led to the gauge and to the oxygen cylinder had been pierced at the bend and flames had come out. On taking the bomb to pieces afterwards it had been found that the spindle which served to close the bomb had been " washed " away, as was usual in an explosion. The experiment had been repeated with another lid which he had added to the bomb. Everything went well, but in order to corroborate the matter, another experiment had been made, and then there had been a very violent explosion, which had had the following effect: the hole in the lid through which the oxygen was admitted was originally about 1 millimetre in diameter; the explosion had increased this to about 6 millimetres in diameter. The steel spindle which passed through a stuffing-box and screwed down to close the 1 millimetre opening in the lid, was 6 millimetres in diameter. About 30 millimetres of the lower part of this spindle had been " washed away " through the central channel of the upper part of the spindle, which still remained fixed in the hollow pillar of the lid, but the union-nut connecting the spindle to the tube from the oxygen cylinder was smashed.

The explosion took place during the charging of the bomb with oxygen, before the pressure had reached 10 atmospheres, and there was no possibility of the explosion having been caused by a spark. It was one of the most extraordinary effects he had ever seen.

Unfortunately there had been only a very small quantity of the petrol available, and he had not been able to make any further experiments with it. He did not know whether any other member had had a similar experience.

Dr. F. B. Thole congratulated the author on the publication of data of great scientific and general interest, and mentioned that uniformity of temperature could be achieved more quickly if the apparatus was constructed of brass, whilst admission of the oxygen by a narrow channel drilled directly through the metal to the central cavity would ensure thorough pre-heating.

The choice between the adoption of air or oxygen was a difficult one, for although oxygen afforded more consistent figures, which were less affected by barometric changes, yet the results were less discriminatory than with air, a matter of importance when small differences in ignition-point are under investigation.

The author rightly emphasised that the results are only relative. It must be remembered that the effect of variation of pressure is considerable, and in comparing two fuels (especially if they differ in chemical nature), it is quite conceivable that whilst one may have the higher ignition-point at ordinary pressures, the order may become reversed under the pressure of 100 lbs. attained during the compression-stroke in a high-compression petrol-engine. It is noteworthy that cracked spirit, which has a lower ignition-point at ordinary pressures than a straight-run petrol of corresponding boiling-point range, shows less tendency to cause "knocking" when used as a motor fuel.

An apparatus capable of determining spontaneous ignition temperatures at pressures variable at will would be of the greatest value.

The speaker could fully confirm Mr. Moore's conclusions regarding the negligible effect of varying the lining of the test cavity, and regarding the ease with which the temperature of the heating block can be accurately measured.

The following additions could be made to the interesting data regarding ignition-temperatures given in the paper:—

1. With pure paraffins (pentane, hexane and heptane) the difference between the ignition-temperatures in air and oxygen was about 200° C.

2. Cycloparaffins had ignition-temperatures appreciably higher than the paraffins of similar boiling-point.

3. Olefinic hydrocarbons ignited much more readily than paraffins of similar boiling-point.

4. Many other sulphur compounds besides carbon disulphide have

abnormally low ignition-temperatures. Diethyl sulphide, for example, has a very low ignition-point which is approximately the same in air or oxygen (compare turpentine).

The author's generalisation that substances with a low ignition-temperature pass through a stage of partial oxidation with consequent excessive local heating is at present based on very slender evidence, and would hardly account for the low ignition-temperature of sulphur.

The data given for mixtures of liquids are of great general interest, especially perhaps in the case of benzol-petrol. The most striking feature was the very small increase in ignition-temperature resulting from the addition of 50 per cent. of benzol to the more easily ignited petrol in contrast with the great depressing effect of a much smaller proportion of petrol added to benzol. The contrast brings out forcibly the problem underlying this investigation : How do the data afforded by ignition-temperature tests compare with the results of actual engine-tests ? As a result of parallel tests with various aviation-spirits, examined as regards ignition-temperature at ordinary pressure and in a high-compression aero-engine, it may be stated that the former is the less sensitive ; an alteration in the composition of the spirit too slight to affect measurably the spontaneous ignition-temperature produced a noticeable change in the running of the engine.

Mr. E. A. Evans said he would like to ask the author whether, during the determination of the ignition-temperature, he considered it was either the oil or the vapour which ignited. Also if one heated a volume of oil up to its ignition-point, would it ignite spontaneously ? If it would, it threw some interesting light on lubricating questions. One was frequently asked for the flash-point of an oil, because people had an idea that the risk of fire depended upon the flash-point. He did not think it did. In the case of an axle-box running hot, it seemed to him that the ignition-point would be a much more valid indication of the safety of the oil than the flash-point. The author had suggested that the ignition-point was an indication of the stability of an oil. That might be so from a fuel-oil point of view, but had it any bearing upon the stability of a lubricating oil in relation to its liability to carbonise in use ? It might be extended to that, because that was frequently the test which was applied to lubricating oils.

The author stated there might be a silent combustion taking place before the actual ignition-point was reached. There had been a series of articles published by F. C. Phillips in the American *Chemical Journal* about 1894 dealing with the oxidation of gases, and the

temperatures which Phillips had obtained had been very low. How Phillips had done it, he thought, was that he mixed the gases with air, and passed them over various metals, and he found that the temperature at which carbon dioxide was evolved was distinctly low. With hydrogen it was something in the neighbourhood of 100° C., whereas if the gas were moistened it would begin to oxidise at atmospheric temperatures. Phillips had taken various other gases, and had passed them over various catalysers, and had found that the temperature varied very considerably with the metal used.

Mr. N. A. Anfilogoff said the author's experiments were, of course, a step in the right direction. He desired merely to emphasise a point which had been raised by Dr. Thole. The members had seen a number of graphs showing the ignition-points of the various oils and petrols and mixtures. In the instrument the author had designed a drop of oil was burning, or exploding or igniting in an unknown quantity of either oxygen or air. In the Mahler bomb or any other bomb-calorimeter one had the same small quantity of petrol igniting and burning in a definite quantity of oxygen. The volume of the bomb was known and the quantity could be calculated; but to say that the diagrams and the graphs gave one very much to go upon with regard to the ignition-point of the petrol actually in the petrol engine was not, he was afraid, quite proven, because, after all, the petrol did not get in to the internal-combustion engine in drops, but entered the combustion-chamber partly as a mixture of air and petrol vapour, and partly in very fine atomised drops. He would like the author to say whether the comparisons of the graphs upon the practical scale and the theoretical scale had been worked out, with due regard to the fact that one had in the internal-combustion engine through the carburettor partly a mixture of air and petrol-vapour, and partly actual atomised drops of petrol.

Dr. R. Lessing asked whether all the oil that was dropped into the crucible before the explosion actually took place disappeared entirely in all cases, even in the case of heavy oil, or whether any crust of carbon or other solid or liquid cracked product was formed; if that did not happen, it appeared to him that rather more of the silent combustion took place than the author assumed in most cases. That led up to one other aspect of the theory of the test. He did not wish to refer to the radiation theory of catalysis mentioned by Dr. Ormandy. The point he wished to raise was: At the temperatures just below the ignition-point and the spontaneous ignition-point did hydrogenation, or dehydrogenation, take place? It

might be quite likely that the property of splitting off hydrogen was one that was pertaining to each substance at one particular temperature, and that the decomposition-products in their turn might be more susceptible to violent oxidation than the substance itself before it was so decomposed.

Mr. Moore, in reply, said Mr. Chaloner's slide had been very interesting; but at the same time he (Mr. Moore) did not think that Rieppel had been the first to make the test. He believed that Victor Meyer had worked on the subject previously, and he doubted whether there had not been others who had worked on the test before Rieppel had actually come on to the work.

Personally, in the design of his instrument he had examined all the results that had been published, and had made use of them for his own purpose. The great drawback in regard to Constam and Schläpfer's apparatus was that the range of experimental error was extremely high. The reason for that was that the capacity of the crucible was very small, and that therefore the adding of a drop of fuel might considerably depress the temperature of the inner crucible itself. What was required was a comparatively large block of metal to raise the oil to the necessary temperature, and stabilise the conditions. He himself had used a 4 in. block of steel bar, and the effect of one drop of oil was not appreciable on the temperature of the instrument, but if one used a 30-gramme platinum crucible, one drop of oil caused all the temperatures to vary considerably, and increased the error up to the figure which Constam and Schläpfer allowed, of plus or minue 30°.

Dr. Ormandy had called attention to the variation in results which was caused by varying conditions. He thought Dr. Ormandy had not mentioned the size of the source of heat, a factor of great relevance. As far as he (Mr. Moore) could see from the results of the many experimenters who had worked on the subject, the two overwhelmingly important factors controlling the results which one obtained in ignition-point determination were (1) the size of the source of heat, as for example, with a spark (it was not purely the temperature of the spark, but its size; the thickness of the platinum wire influenced results); and (2) the time of exposure.

Several speakers had drawn attention to the question of silent combustion, and the fact of intermediate oxidation taking place. He thought that phenomenon probably occurred in all spontaneous ignition. It was not really the ignition-point of the substance that one obtained; he had simply used the term "ignition-point" as a name for the result of the experiment. Probably the internal dynamics of the reaction which was taking place was much more

complex. The oxidation might go through half a dozen stages before it finished as water and carbon dioxide.

Judging from other people's results, the effect of the time interval became pretty obvious. Probably combustion took place, and some reaction occurred which caused a heating-up effect. The ignition-point obtained in the instrument was when the heat increment due to the generation of heat by the oxidation of the compound in whatever change was taking place exceeded the leakage of heat from the system. For that purpose he used a heavy block to stabilise the conditions. He had only attempted to obtain relatively correct results.

With regard to the time factor, a large number of gas people who had made researches on ignition-points of gases had stated that they have tried to minimise the time. As far as he could see, taking a general view of all published results, the smaller the time the higher the temperature.

He had been very interested in Dr. Ormandy's explanation, but he was going to study it very carefully before he accepted it. He had also been interested in Mr. McNab's bomb. He could not explain why it should have ignited. He happened to know of a case of a Diesel engine which it had been attempted to start with oxygen, and the starting cylinder, containing oxygen at a pressure of about 600 or 700 lbs. per inch, blew up, killing one man and injuring several others. There had never been a satisfactory explanation of the conditions, but they seemed to agree most closely with those of Mr. McNab's bomb. There had been the same needle-valve, the same thin copper pipe, and the same explosion. The origin of it was exceedingly difficult to discover.

In reply to Dr. Thole, he did not know that brass had a particular advantage. In the first place, with regard to the question of conduction, there was quite sufficient conduction in a 4 in. × 4 in. block of iron or steel. There was no appreciable variation in temperature between one side of it and the other. He had had a block tested in many different positions with thermometers, thermo-couples and resistance-pyrometers, and he thought one corner of a block of those dimensions was of the same temperature as the others, so he doubted whether there was much advantage in employing a brass block. He also doubted whether brass would stand 700° C. for a prolonged period as satisfactorily as iron.

With regard to the question of using oxygen or air for the trials, he had adopted oxygen as a standard, first because he thought it more closely approached to engine conditions, and secondly because it gave less experimental error. He quite appreciated that the

curves of the mixtures of petrol and benzol might not have the same inclination to the curve (i.e. the same rate of change) as results obtained from engine trials, but as a generalisation his rules held good, he thought, for the effect of ignition-point of compression. He had done a very large number of engine compression-trials himself on the point, but not petrol engines. He had compiled his petrol-engine curve from other people's results. He had made the Diesel engine curve by engine-trial himself, varying the compression up and down between limits of somewhere about 400 and 680 lbs. Provided that the spontaneous ignition in the meter was a continuous function of the engine figure, it did not matter whether it was varying at a different rate, if one prepared a curve for any particular type of engine in the nature of the curve with the E F, E D, and A B lines on it. The curve must be made on experimental results, after which one could plot back compression-pressures from the ignition-points of the fuels. One could not calculate compressions direct from the ignition-points, except by the use of a curve which had been obtained in practice from engine trials. The lines A B and C D which were on the curve, had been obtained from practical engine trial results.

With regard to the effect of cracked spirit, he had not any figures. He had been surprised to hear that cracked spirit would withstand a higher compression than straight-distilled spirit. He had always understood that cracked spirit required a slightly lower compression. In any case the ignition-points were very little different. With reference to the determination of the ignition-point under pressure, if a satisfactory pressure-figure could be obtained, it would certainly be a great improvement on this instrument, but it was not very easy to secure. He had made a very large number of attempts to obtain spontaneous ignition-temperature results under pressure, but he had given it up. The new figures which had been given were very welcome. He was always glad to hear of new figures.

With regard to di-ethyl sulphide, he did not know why it should be considered that it did not undergo an intermediate reaction during the test ; he should think it was a very likely body to do so. He did not happen to know enough about it to say definitely that it did go through a partial-oxidation product, but sulphur-compounds were sufficiently unstable in all respects to justify the expectation of a partial oxidation.

In reply to Mr. Evans' question whether it was the residue or the vapour which caused the ignition-point, he rather thought it was the heavier vapour, but he was not quite sure. Certainly the residue had a very low ignition-point. Captain Sinnatt had made

a large number of tests on coal, and had read a paper in Manchester about a month ago. He had used one of the instruments designed by the author for oil testing. The coal figures were a great deal lower in temperature than the oil ones. The period of wait, that was to say, the time between adding the substance and obtaining the ignition, was a great deal longer than that obtained when testing liquid fuels. In some cases they ran to over a minute, so probably the residue had some effect.

With regard to the ratio between the oxygen- or air-supply, and the quantity of oil taken, in the case of determination of ignition-points of gases, the majority of experimenters had to decide what ratio was going to be employed before making the test. In the author's instrument a small amount of oil was employed, with an excess of oxygen. During the test, one had a spot of oil lay on the floor of the crucible. Outwards from the centre of that drop, was zones of oil-vapour containing a little oxygen, of oil vapour with half oxygen, and finally into oxygen with only a trace of oil vapour. The ignition of the oil obtained is from the mixture which has the lowest ignition-point. That was the figure really required for engine purposes.

With regard to the effect of catalysis, he had feared that catalysis would greatly influence the result, but from the standardisation-experiments mentioned in the paper it did not seem to have had such an effect as might have been expected. After using a very large number of different substances, in no case could he find that the difference between using one substance and another for the crucible was sufficient to be really in excess of the experimental error, which was plus or minus 8°.

COMMUNICATED.

The solubility relations of Castor Oil and Petrol from various sources.

By William Ringrose Gelston Atkins.

When two pure partially miscible substances such as water and phenol are mixed a regular curve is obtained correlating miscibility and temperature.

In connection with the use of castor oil and various petrols and kerosenes for certain industrial purposes it appeared advisable to carry out an investigation of their behaviour when mixed. It has

been stated that castor oil is practically insoluble at 15° C. in petroleum spirit and in burning oil. It has also been pointed out that castor oil is able to dissolve mineral spirit and burning oils in proportions which decrease as the specific gravity of the mineral oil increases. The addition however of oils such as rape, tallow or lard brings about miscibility (Archbutt and Deeley, "Lubrication and Lubricants," p. 122).

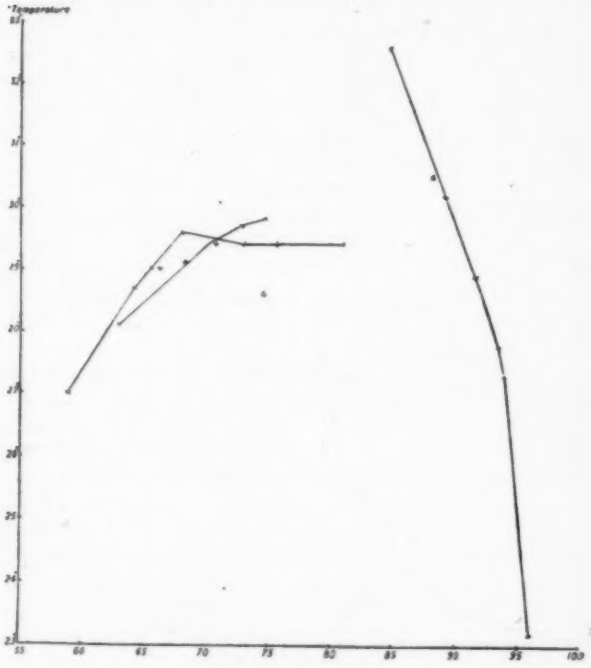
Direct trial, however, with a sample of pure pharmaceutical castor oil of low acidity and normal characteristics and a sample of petrol $D\frac{15}{15}0{\cdot}722$ showed that these two liquids were miscible in all proportions at air temperature. The petrol was of Eastern origin, and it appeared probable that the petrol mentioned in the literature was of American origin. Steps were accordingly taken to ascertain the influence of the composition of the petrol.

General Account.—Petrol from the East Indies, Egypt and Europe (Rumania or Galicia) was shaken up with castor oil. In each case miscibility was complete at room temperature whatever the proportions.

The Sumatra and Egyptian petrols were then distilled through a five section Young evaporator stillhead, and it was found that the fraction coming over below 52° C. afforded no critical solution point with castor oil, for at atmospheric pressure this temperature lay above the boiling point of the chief constituents of the fraction. The fractions collected between 52° and 90° were found to give critical solution points at 32·2° for the Sumatra and at 31·6° for the Egyptian petrol. Above 104° to 144° the fractions were miscible with castor oil in all proportions. It is thus clear that the presence of certain substances, particularly in the higher fractions, increases the mutual solubility of petrol and castor oil by lowering the critical solution temperature.

In order roughly to ascertain the form of the curve relating to composition and temperature of complete miscibility a weighed amount of castor oil was taken in a test tube and to it definite volumes of the fraction of Egyptian petrol between 52° and 90° were added. The temperature of miscibility was observed for each mixture. Owing, however, to the loss of petrol of low boiling-point the resulting liquid contains a preponderance of the higher boiling constituents. Two curves as shown in fig. 29 were obtained in this way. The third curve was obtained by combining the concordant results of two other sets of measurements in which the percentage of oil was from the start very small. It may be seen that at room temperatures about 55 per cent. petrol and 45 per cent. castor oil form a homogeneous mixture. That is to say the oil dissolves more

than its own weight of the petrol fraction. The latter, on the other hand, dissolves a bare 4 per cent. of oil. Since the fraction used was an arbitrary selection it did not appear to be worth while to determine the form of the curve more accurately, especially as however rapidly the determinations were made it would be impossible to avoid losing some of the more volatile portion from an open



Per cent. Petrol.

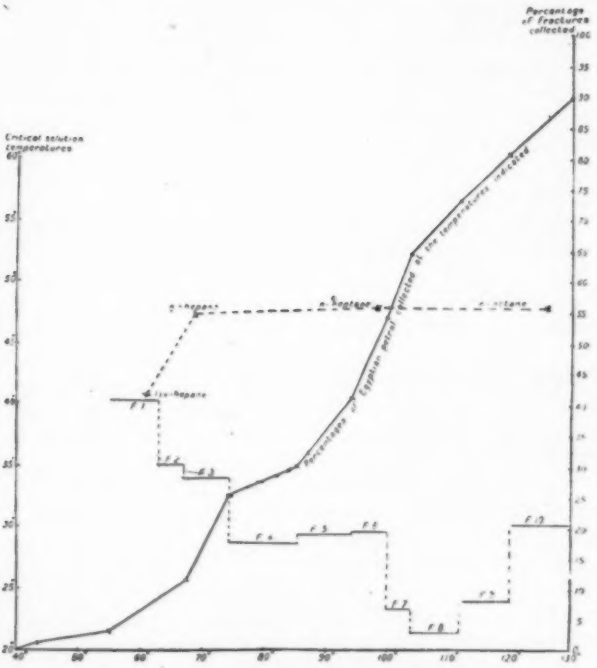
Solubility Relations of Castor Oil and Petrol (52°—90°C.)

Fig. 29.

test tube. The critical opalescence was observed from 29·0°, with 66 per cent. of petrol to 29·8° with 74 per cent. The best opalescence was observed at 29·4°—29·7°, between 70·7 and 72·9 per cent. of petrol. Allowing for loss by evaporation the critical composition cannot be far from 70 per cent. of petrol fraction, and the critical temperature may be taken as 29·5°. The maximum point observed

was 32·6°, but this depends on the rapidity with which the determination is carried out.

A systematic examination was then made of the fractions of the Egyptian petrol lying between the mid-way points of the boiling-points of the supposed major constituents. The results are shown in fig. 30, as are also the distillation percentages over the various



Temperature of collection of fractions
Critical Solubility Temperature of Castor Oil with Petrol fractions and with pure paraffins.

FIG. 30.

ranges for Egyptian petrol. The Sumatra and European samples yield very similar curves which have been omitted. The European is slightly the more volatile. In this figure are also shown the critical solution temperatures of castor oil and the following:—*n*- and *iso*-hexane, *n*-heptane *n*-octane. The normal paraffins

differ but little in their critical solution temperatures, which lie at 47·3, 47·9 and 47·8 respectively, that of *iso*-hexane being at 40·8, a value which may be slightly low owing to a small amount of impurity. Iso-pentane boils away before its critical temperature is reached. Details of the substances used are given in the Experimental portion of the paper. Castor oil is miscible in all proportions with benzene and toluene, also with pentamethylene.

It is obvious that the explanation of the low temperatures found for the petrol fractions yielding maximum points with castor oil lies in the fact that the aromatic and naphthene compounds lower the miscibility temperatures of the paraffins. It may be pointed out, for example, that while the fraction 55°—62° gives a maximum point which almost coincides with the critical solution point of *iso*-hexane, yet there is a considerable lowering in the region in which *n*-hexane and benzene come over, namely, 62°—75° and a still greater lowering around 80° where hexamethylene is collected.

Variations in the castor oil used also affect the critical solution temperature; that for an abnormal sample of low viscosity and density, but normal with regard to iodine and acetyl values and of high acidity was found to be 31·1° as against 32·2° for a normal castor oil with the same petrol fraction.

I desire to acknowledge my indebtedness to Prof. S. Young for his kindness in providing me with the pure liquids used and for his advice throughout.

Experimental.—The pure or approximately pure liquids used for the determinations were as follows :—

Iso-pentane, Kahlbaum.

Iso-hexane, a fraction obtained from American petroleum by Prof. S. Young, b.p. 61·0—61·3. It probably contains two isomers.

n-hexane, a pure sample obtained by Prof. Young from American petroleum, b.p. 68·95.

n-heptane, a pure sample prepared by Prof. Thorpe from *Pinus sabiniana*. The b.p. of the pure substance is 98·43.

n-octane a nearly pure sample fractionated by Prof. Young from the synthetic product supplied by Kahlbaum. The pure liquid boils at 125·8°.

Pentamethylene, D^{20}_{4} 0·7239 the greater part boiling at 49·5°. It contains a little tri-methyl ethylmethane. It was also prepared from American petrol by Prof. Young.

In the following table are shown the constants determined for the Egyptian petrol used in constructing fig. 2. The sp. gr. recorded is at 17·5° relative to water at 15·5°.

Distillation range.	Sp. gr.	Maximum point.	Best opalescence.	Fractions per cent.
To 43°	0·6355	—	—	1·8
43°—55°	0·6524	—	—	1·7
55°—63°	0·6653	40·3	39·6	5·7
63°—67°	0·6857	35·1	34·3	2·6
67°— 74·6°	0·6917	34·0	32·6	13·8
74·6°—85·5°	0·7133	28·8	27·7	6·4
85·5°— 94·3°	0·7207	29·5	28·5	9·8
94·3°—100°	0·7253	29·7	28·5	12·4
100°—104°	0·7356	23·4	22·8	10·9
104°—112°	0·7437	21·5	—	8·6
112°—120°	0·7450	24·1	23·5	7·4
120°—130°	0·7422	30·2	28·5	8·3
Residue	—	—	—	10·9

The behaviour of castor oil to petrol constituents appears to be similar qualitatively to that of aniline as shown by Chavanne and Simon (*Compt. rend.* Juin 2, 1919, *et. seq.*). The author wishes to acknowledge his indebtedness to these investigators for allowing him to see these results ten months before publication.

TRINITY COLLEGE, DUBLIN,
May 30th, 1919.